Title

Economic Spillovers of Highway Investment: A Case Study of the Employment Impacts of Interstate 105 in Los Angeles County

Author
Chalermpong, Saksith

Publication Date
2002-11-01

UNIVERSITY OF CALIFORNIA, IRVINE

Economic Spillovers of Highway Investment: A Case Study of the Employment Impacts of Interstate 105 in Los Angeles County

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSPHY

in

Transportation Science

by

Saksith Chalermpong

Dissertation Committee:
Professor Marlon G. Boarnet, Chair
Professor Kenneth Small
Professor Herbert Mohring

2002

The dissertation of Saksith Chalermpong
is approved and is acceptable in quality
and form for publication on microfilm:

Kenneth A. Small

Herbert Mohring

Marlon G. Boarnet
Committee Chair

University of California, Irvine
2002

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I am grateful to Professor Marlon Boarnet for all his guidance and unwavering support. He always worries about my welfare, academic or otherwise. He has given me countless opportunities to broaden my experience and knowledge. He is truly my mentor.

I am also indebted to valuable advice from the committee members, Professors Kenneth Small and Herbert Mohring. Ken is by far the best teacher and researcher in the field of transportation economics. Herb always offered many insightful comments. I learned a great deal from both of them.

I thank Rick Funderberg, Elizabeth Geho, Lyn Long, and Tracy McMillan – my officemates, neighbors, and friends, who painstakingly helped with copyedit works and always provided much support. I also thank my friends Andres, Ken, and Eyre for making my life eventful and at times bearable in Irvine and beyond. Those from MIT, John, Stanley, Jen, Tai, and P'Ae always called to check that I am still alive and well. My old friends from Chula, Gob, Tony, and MuEE visited from time to time and are always great company.

I am thankful to the Royal Thai Government, the U.S. Environmental Protection Agency, the University of California Transportation Center, and the Regents of the University of California for providing financial support at one point or another over the three-year period at UCI.

Finally, I wish to thank my parents and my sister for all their encouragement through this long endeavor.

SAKSITH CHALERMPONG

EDUCATION

UNIVERSITY OF CALIFORNIA — Irvine, CA
Doctor of Philosophy in Transportation Science — November 2002
Dissertation Title: Economic Spillovers of Highway Investment: A Case Study of the Employment Impacts of Interstate 105 in Los Angeles County
Dissertation Committee Chair: Marlon G. Boarnet
Dissertation Committee Members: Kenneth A. Small and Herbert Mohring

MASSACHUSETTS INSTITUTE OF TECHNOLOGY — Cambridge, MA
Master of Science in Transportation — May 1998
Thesis Title: Urban Congestion and Firms' Decentralization
Thesis Supervisor: William C. Wheaton

CHULALONGKORN UNIVERSITY — Bangkok, Thailand
Bachelor of Engineering in Civil Engineering — March 1995

RELEVANT POSITIONS HELD

UNIVERSITY OF CALIFORNIA — Irvine, CA
Graduate Student Researcher assisting Professor Marlon G. Boarnet — 1999 – 2002

MASSACHUSETTS INSTITUTE OF TECHNOLOGY — Cambridge, MA
Research Assistant to Professors William C. Wheaton and Nigel H.M. Wilson — 1997 –1999

CENTRAL TRANSPORTATION PLANNING STAFF OF BOSTON METRO AREA — Boston, MA
Regional Transportation Planning Analyst — Summer 1999

CHICAGO TRANSIT AUTHORITY — Chicago, IL
Transit Service and Operations Planning Analyst — Summer 1998

SELECTED PUBLICATIONS

JOURNAL PAPERS

Boarnet, M. G., and Chalermpong, S. (2001) "New Highways, House Prices, and Urban Development: A Case Study of Toll Roads in Orange County, CA." *Housing Policy Debate*, 12(3), 575-605.

Boarnet, M. G., Chalermpong, S., and Geho, E. (2002) "Specification Issues in Models of Population and Employment Growth." Submitted to *Papers in Regional Science.*

CONFERENCE PAPERS

Chalermpong, S. (2001) "Economic Spillovers and Highway Finance Reform: Is Decentralization of Highway Finance Appropriate?" Presented at the Association of Collegiate School of Planning 43rd Annual Conference in Cleveland, OH, November 2001.

Boarnet, M. G., and Chalermpong, S. (2000) "New Highways, Urban Development, and Induced Demand." Presented at the Transportation Research Board 79th Annual Meeting in Washington, D.C., January 2000.

Boarnet, M. G., and Chalermpong, S. (2002) "Urban Growth and Highway Infrastructure: A "Before" and "After" Test of the Influence of Highways on Metropolitan Growth Patterns." Presented at the 49th Annual North American Meetings of the Regional Science Association International in San Juan, Puerto Rico, November 2002.

ACADEMIC AWARDS

UNIVERSITY OF CALIFORNIA REGENT'S FELLOWSHIP
Dissertation Fellowship, Summer 2002

UNIVERSITY OF CALIFORNIA TRANSPORTATION CENTER
Doctoral Dissertation Research Award, September 2001

THE FANNIE MAE FOUNDATION AWARD
Best paper on housing and community development at the ACSP 2000 conference, November 2000
Paper Title: New Highways, Urban Development, and Induced Demand (with Marlon G. Boarnet)

THE ROYAL THAI GOVERNMENT
The Royal Thai Government Scholarship, September 1996

CHULALONGKORN UNIVERSITY
Faculty of Engineering Academic Honors, May 1995

ABSTRACT

Economic Spillovers of Highway Investment:

A Case Study of the Employment Impacts of Interstate 105 in Los Angeles County

By

Saksith Chalermpong

Doctor of Philosophy in Transportation Science

University of California, Irvine, 2002

Professor Marlon G. Boarnet, Chair

Most economists agree that new investments in highways at this point in time in the United States have little impact on overall growth in output. New highways play a more important role in shifting economic activities among places, drawing jobs from other locations into the highway corridors, a phenomenon known as negative spillovers. The objective of this dissertation is two-fold, to examine the proposal to decentralize highway finance, which aims to solve the financial responsibility mismatch problem that stems from economic spillovers of highways, and to test the hypothesis of economic spillovers of highway investment at the metropolitan level. First, to better understand how spillovers influence the highway investment decision, the theorctical framework from the interjurisdictional tax competition literature is borrowed to model governments' investment behaviors. Numerical simulations show that decentralized local governments, which independently maximize output in their own jurisdiction, may engage in wasteful investments in highways with the presence of spillovers. Second, to shed more light on the spatial detail of economic spillovers, empirical tests of the spillover hypothesis are conducted at the metropolitan level, with census tracts as the unit of observation. The results of the quasi-experiment reveal census tract employment growth patterns that confirm the existence of negative spillovers caused by the opening of the Interstate 105 in 1993. The benefiting area, which grew substantially after the highway was opened, is limited to a long narrow corridor around the highway, while nearby locations outside the corridor experienced slow growth relative to the rest of the metropolitan area after controlling for various factors. Together, these results suggest that although negative spillovers are present at the metropolitan level, decentralizing highway finance may not be an effective policy to deal with the financial responsibility mismatch problem. Highway finance should remain centralized within metropolitan areas, and regional governing bodies should pay special attention to the distributional impact of highway projects.

INTRODUCTION

A. Motivation

Traditional highway finance is guided by an evaluation process that primarily uses Cost-Benefit Analysis (CBA). By providing measures of social costs and benefits of alternative proposals, CBA helps policymakers understand the various impacts of each alternative project so they may select the project that best serves the social interests. The central issue of CBA is efficiency, and much effort has been devoted to bring CBA closer to providing the best ranking of alternatives with respect to this criterion. Early analysts focused only on directly measurable effects of highway projects. For example, Mohring and Williamson (1969) argued that "... in the United States, direct benefits receive almost exclusive attention in such formal benefit/cost analysis as is undertaken in connection with proposed highway improvements." These "direct" benefits include highway user benefits (travel time and operating cost savings) and safety benefits (reduction in accident and fatalities). On the other hand, capital costs of construction and maintenance mainly constitute the cost side of the analysis. External costs, particularly environmental impacts and congestion, later received attention and are now extensively analyzed in most CBA. Other attempts to refine the analysis include efforts to appropriately assign parameters such as value of time and discount rate and appraise qualitative attributes such as accessibility, land use effect, and aesthetics.

While external costs of highways have recently received much attention in the evaluation process, indirect benefits from highways have largely been ignored in the cost-benefit studies. The main reason is the concern of double counting. Central to this concern are non-user benefits, which include land value appreciation, benefits from reorganization of production technology in response to lower transportation costs, firm agglomeration benefits, and increases in employment and other economic activities.[1] Politicians often assert that economic development from highway construction and ensuing employment should be grounds for adopting a project. However, most scholars believe that these indirect benefits should be ignored because they are derived from users' benefits, and therefore, already been incorporated in the CBA. Herbert Mohring's (1961) early work on the impact of transportation improvement on residential land markets inspired the rationale for exclusion of economic development impacts as benefits.. Over years, other researchers followed his lead and investigated other types of economic impacts of highways, although most research involved the impact on land markets.

Despite the improvement in the process of highway project evaluation, the current practice remains flawed in two critical areas. First, using Cost-Benefit Analysis (CBA) as a primary tool for evaluation, practitioners still fail to assess certain external costs and benefits, in particular, economic impacts of highways. Second, distribution impacts are often overlooked due to the heavy reliance on efficiency criteria. Specifically, the relocations of economic activities in response to highway benefits, direct or otherwise, are almost entirely ignored. Practitioners rarely incorporate these economic assessments in the project evaluation and many identify difficulty of analysis as a reason for such omission. However, given the dwindling amount of funds for transportation investment, it is more critical than ever that the process for allocating the limited resource be nearly perfect. Therefore, improvements in project evaluation in these two areas are clearly needed. This dissertation contributes to the field by theoretically and empirically

[1] These benefits are sometimes referred to as economic development benefits.

examining the two intertwined aspects of the problem: the economic development impacts of highways and the distribution effects that ensue.

B. Economic Impacts of Highways

Highways impact a variety of markets through different processes. Over the past few decades, many researchers have examined various aspects of economic development impacts from highways. This section provides an overview of theories regarding these effects.

1. Land Market

In his pioneering work, Mohring (1961) argued that, although land near new transportation infrastructure generally appreciates from an improvement in accessibility,[2] the improvement might not increase aggregate land values due to depressed land values elsewhere. He demonstrated that the aggregate land values equal half of aggregate transportation costs in a monocentric bid-rent model that assumed both lot size and trip rate per household as fixed. Thus, the reduction in transportation costs due to transportation improvement decreases the aggregate land values by an amount equal to half of the cost reduction. Mohring concluded that land value appreciation should not be considered additional benefits from highway projects if no normative goal for such redistribution among members of society exists. His conclusion highlights the importance of distribution considerations even when efficiency is not an issue.

Wheaton (1977) produced similar results using a general equilibrium approach. He argued that compensating variation – the amount required to fully compensate consumers for losses resulting from an improvement – appropriately measures

[2] Except for land immediately adjacent to the highway where noise and air pollution may offset the appreciation due to improved accessibility.

transportation improvement benefits in the long-run. This measure alone would be sufficient for benefit calculation of highways in general equilibrium because any adjustment in an adjoining market, such as the residential land market, would be already incorporated. Therefore, considerations of increases in land value would not be necessary. To prove this point, Wheaton employed a monocentric bid-rent model assuming homogeneous households. Wheaton also incorporates consumption of other composite goods in addition to the transportation and residential land sectors explored in Mohring's partial equilibrium model. Furthermore, the model allows for variable lot size; i.e., land consumption adjustment is possible in response to changes in travel costs (and hence income) and endogenous rental income. His analysis of the effect of changes in transportation cost on household's utility and income show that the value of transportation improvement in the form of "income compensation" is equivalent to the change in income-compensated travel-demand consumer surplus. Therefore, he concluded that the changes in residential land value due to an improvement can be completely ignored if the change in consumer surplus is counted as a benefit of transportation improvement.

Martinez and Araya (2000) examined an assumption, which has been used by previous researchers, that firms and households choose their location to minimize transportation costs. This assumption implies a perfect capitalization of transportation cost saving into land value. The authors argued that evidence does not support the assumption and both firms and households may be more sensitive to location-specific factors other than transportation access. For example, house buyers may be interested in school quality, environmental quality, public safety, and social and cultural activities that are location specific. In this case, transportation user benefit (transportation cost saving) may, in Martinez and Araya's word, "percolate" into land value only partially. This means that while some of the transportation cost saving benefits are transferred to landowners, the rest are retained by the transportation users. The degree of "percolation" depends on the sensitivity of the population to transportation access.

Relevant to the current practice of transportation project evaluation, Martinez and Araya preferred user benefits over land benefits as a measure of benefits from transportation projects, based on the fact that land value appreciation does not fully capture transportation cost saving. However, they also elevated concern about the use of travel demand models that do not account for land use and technological externalities (e.g. agglomeration) to estimate user benefits. Because transportation projects can affect development – firms' and households' location decisions, and hence, travel patterns – user benefits that are forecasted from this type of travel demand model may not be accurate. For example, if agglomeration benefits are not considered in the model, the forecast traffic volume may be too low and the estimated user benefits will be lower than the actual benefits. For this reason, Martinez and Araya suggested that travel demand models include an integrated land-use system to estimate transportation user benefits for the purpose of the transportation project evaluation.

2. Industrial Reorganization

Mohring and Williamson (1969) introduced the notion that transportation improvement can induce industrial reorganization. Since transportation is an input to production of all goods, its improvement, i.e., the reduction in its price, can have significant impacts on how manufacturing firms use transportation infrastructure and other production factors. In industries where scale economies prevail, lower transportation costs reduce firms' distribution costs and encourage firms to enlarge plant size to achieve lower average costs in the long run. The larger plant size firms require more transportation for distributing products, but the benefits of producing greater volumes can offset the increase in distribution costs if the reduction in transportation cost is great enough.

Another example pertains to production technology innovation. The change in relative input prices induced by transportation improvements could have a more profound effect on firms than simply plant size adjustment. Cheaper and more reliable transportation might stimulate firms' innovation in production technology; Just-In-Time (JIT) production provides a good example. Innovation will benefit consumers via lower price of goods. Despite the variety of ways transportation improvements impact production technology, Mohring and Williamson showed that "industrial reorganization" benefits are merely transfers of user benefits to another form.

3. Consumer Benefits in Monopolistic Market Condition

Jara-Diaz (1986) argued that transportation improvement might benefit consumers in a previously isolated market by providing access to excess supply of goods in other markets. Similarly, the improvement could permit suppliers to access excess demand in previously inaccessible markets. He explored the relationship between the change in transportation consumer surplus (user benefits) and increases in social welfare (consumer and producer surpluses) that result from price changes in the consumer market induced by transportation improvement. He demonstrated that the change in transportation consumer surplus, ΔTCS, exactly equals the improvement in social welfare, ΔW, under competitive market conditions.[3] Under monopolistic market conditions, however, ΔW exceeds ΔTCS. Jara-Diaz also showed that the extent that the economic benefits (ΔW) deviate from user benefits (ΔTCS) depends on the elasticity of demand as well as the condition of the market (the degree of competitiveness, or alternatively, monopoly power). The difference between ΔW and ΔTCS will be largest when the market is purely monopolistic and demand perfectly inelastic. In the more likely case where the market situation and demand elasticity lie somewhere between the extreme conditions, the deviation will be small, and under certain conditions, the difference will be negligible.

A brief review of the literature reveals that a majority of transportation economists embrace the idea that non-user economic benefits are derived from direct user benefits. As such, non-user benefits simply reflect the transfer of direct user benefits to other members of society. A recent international survey of transportation project evaluation published in *Transport Policy* (January 2000) demonstrates the broad dissemination of this scholarly belief into transportation planning practice. The survey reviewed the practice in several industrialized countries, i.e., the USA, France, Germany, Japan, the European Union, and the UK, as well as the practice in the developing world as recommended by the World Bank. Each country's representative identified the concern of double counting as a rationale for excluding economic benefits from the evaluation process. Germany is the only survey participant that indicated it evaluated regional economic benefits, and this is done only in extraordinary cases of lagging regions.

The literature also shows that economic impacts can vary significantly over space. Therefore, analysis of economic impacts is necessary for distribution as well as

[3] Another underlying assumption for this result is that the welfare weight of benefit recipients equals the reciprocal of their marginal utilities of income.

efficiency considerations in project evaluation. Attempts to improve measurement of transportation projects' contribution to economic growth are sparse because such evaluation is analytically difficult (Vickerman, 2000). For example, Kenneth Small (1999) argued that analysts should focus on direct and clearly measurable user benefits, rather than attempting to forecast the economic impact with large margin of errors, due to the difficulties in predicting such indirect impacts as economic benefits of highways.

C. Distribution Effects of Highway

To judge whether a transportation project improves social welfare, we must evaluate its impact on welfare distribution in addition to its contribution to economic efficiency. Ideally, this task requires knowledge of a social welfare function that ranks all possible combinations of welfare for each member of society. Some economists argue that such a welfare function does not exist; others discredit the approach due to general lack of consensus in describing the function. Yet, most economists concur that a distribution of welfare that society believes "just" or "equitable" is desirable, even though subjective value judgment must be exercised in deciding what is just" or equitable. Therefore, a good project evaluation process must include analyses of how impacts are distributed among members of the population as well as an accurate measurement of social costs and benefits of the transportation project.

1. Current Treatment of Welfare Distribution in Transportation Project Evaluation

Unfortunately, the current practice in evaluating transportation proposals relies heavily on the efficiency criterion through Cost-Benefit Analysis that does not explicitly consider welfare distribution. Choosing a proposal based on the efficiency criterion ensures that net social benefits are maximized. Maximizing net benefits is considered socially optimal because gainers from the implementation of the proposal could compensate losers and still remain better off. However, there is no guarantee that winners will compensate losers. Therefore, the efficiency criterion is insufficient to evaluate matters of distribution.

Most project evaluation analysts often identify the winners and losers, but they rarely quantify the extent of gains and losses each party experiences because measuring these is more difficult.[4] Kenneth Small (1999) argued that, although the gains and losses to each group of the population are difficult to calculate, identifying those who win and lose could help consider equity concerns. If the same evaluation process is applied unselectively to each investment, by knowing the identity of winners and losers, the policymakers can choose the proposals sequentially in such a way that benefit and cost every group of the population alternately. If the same practice is done in every investment program, one might hope that the randomness in gains and losses distribution may lead to evenly distributed impacts over the population.

The 2000 survey on international practice of project evaluation offers a bleak outlook for equity considerations. Researchers often cite the intractability of measuring welfare distribution effects of a transportation project as a reason for not quantifying the amount of gains and losses for various groups of population (e.g., Vickerman, 2000). They argue that the lack of understanding of the issue results in unreliable forecasts, which may be subject to corruptive use for political purposes. The concern has merit, but it does not justify the current lack of attention to the distribution issue. This dissertation argues that problems with distribution and misuse of unreliable forecasts should be dealt with directly by developing better understanding of the issues rather than avoiding these concerns altogether.

2. Localized Economic Gains and Negative Spillovers: Spatial Welfare Distribution

This dissertation advances the economic development impacts of highways as a particularly important type of distributive impact. Mohring (1961 and 1993) is among the first researchers to argue that highways may harm residents of particular locations at the same time they benefit others. The gains in the form of higher land values along a highway corridor may be accompanied by losses in terms of depressed land value at locations distant from the corridor. Forkenbrock and Forster (1991) expanded this idea, arguing that the gains in the form of increased economic activity result from relocation of businesses to advantageous sites along the highway corridors. Although the benefits are observable at the local scale, there may be little change in economic activity within the overall economy. Boarnet (1998) argued that, if highway investment is productive, i.e., areas with larger highway stock are more productive than those with limited highway stock, ceteris paribus, mobile factors will move to areas better endowed in highways and receive higher rent. He formally tested the hypothesis of whether negative spillovers, defined by adverse economic impact on areas distant from the highway corridor, exist, and found that empirical evidence supports the hypothesis. Using a different data set, Chandra and Thompson (2000) confirmed that the negative spillovers of highways are also present in rural areas. The implication of this finding is that highways can have significant redistributive impacts by relocating economic activities, thus creating uneven welfare distribution among members of society.

[4] It is also particularly difficult to predict transfers of benefits and costs among various parties, such as renters and landowners, that are induced by transportation projects. These transfers can be large and are

The lack of distribution considerations in transportation project evaluation, particularly in terms of economic benefits, further complicates current highway finance policy. Specifically, the highly centralized funding program may require taxpayers who live in locations that experience negative spillovers from a new highway to contribute to its funding (Boarnet, 1998). Such cross-subsidies are not only unjust, but also inefficient. With outside subsidies, jurisdictions that potentially benefit from the economic development brought by highways have incentive to overspend on highway stock. This problem can be remedied by better allocation of funding responsibility, but the solution requires better knowledge about who gains and loses from a highway project and the amounts of losses and gains. Clearly, more extensive study on the distribution of economic benefits and losses is needed.

D. Summary

The efficiency criterion of Cost-Benefit Analysis requires that highway benefits exceed costs; however, beneficiaries may be concentrated in small geographic areas because highway benefits are often transferred to other forms of economic benefits. Moreover, evidence suggests that highways can induce economic gains in certain areas by relocating economic activities from elsewhere. This means that benefiting areas may gain at the expense of other places. An equitable funding arrangement of highways for such circumstances would require those who benefit to pay for improvements and not charge those who are harmed. Even more fair, the beneficiaries should compensate those who lose from the highway. In any case, identifying areas of gain or loss from highways is needed to ensure that an investment decision is equitable in addition to efficient.

---

critical for welfare distribution analysis of the projects.

Although indirect economic benefits of highways have been investigated thoroughly, the negative economic impacts[5] have only recently attracted attention of researchers. This dissertation investigates "economic spillovers" as one particular aspect of economic impacts from highway projects. Although this term is sometimes used synonymously for externalities, its intended definition in this research is not necessarily so – spillovers here simply reflect transfers of benefits from one party to another. Such transfers do not imply that particular transportation investments are inefficient; yet, they have critical policy implications on how the projects should be financed. Despite their importance, the current practice of project evaluation rarely incorporates such economic assessments and most practitioners identify the lack of understanding of the phenomena and, hence, difficulties of the analysis as a reason for their omission.

This dissertation contributes to the field by theoretically and empirically examining the economic spillovers of transportation investment. Specifically, its main objective is to answer the question of how highway investments affect local economic activities through the relocation of private factors of production in an urban setting. Unlike previous studies, this research focuses special attention to geographic details, with a fine-grained level of analysis. It employs a quasi-experimental approach to investigate factor growth rates at the census tract level in the Los Angeles Metropolitan Area. The treatment in the quasi-experiment is the proximity to a new highway, Interstate 105 in Los Angeles County (the Century Freeway). The results of the quasi-experiment can help improve our understanding of economic spillovers, which remain relatively under-

[5] There are some exceptions, such as negative externalities from noise and air pollution, which have received much attention and have been well investigated for quite awhile.

investigated in the literature. The knowledge from this study can better inform policymakers in choosing appropriate methods to finance new highways.

References

Boarnet, Marlon G. 1997. "Highways and Economic Productivity: Interpreting Recent Evidence," *Journal of Planning Literature*, 11, 476-486.

Boarnet, Marlon G. and Haughwout, Andrew F. 2000. "Do Highways Matter? Evidence and Policy Implications of Highways' Influence Metropolitan Development" A Discussion Paper Prepared for the Brooking Institution's Center on Urban and Metropolitan Policy, Washington, D.C.

Gramlich, Edward M. 1994. "Infrastructure Investment: A Review Essay," *Journal of Economics Literature*. 32, 1176-1196.

Jara-Diaz, Sergio R. 1986. "On the Relation Between Users' Benefits and the Economic Effects of Transportation Activities," *Journal of Regional Science*, 26, 379-391.

Martinez, Francisco and Araya, Claudio. 2000. "Transport and Land-use Benefits under Location Externalities," *Environment and Planning A*, 32, 1611-1624.

Mohring, Herbert. 1961. "Land Values and the Measurement of Highway Benefits," *Journal of Political Economy*, 69, 236-249.

Mohring, Herbert. 1993. "Land Rents and Transport Improvements: Some Urban Parables," *Transportation*, 20, 267-283.

Mohring, Herbert and Williamson, H. F. 1969. "Scale and "Industrial Reorganization" Economies of Transport Improvements," *Journal of Transport Economics and Policy*, September, 251-271.

Small, Kenneth A. 1999. "Project Evaluation," In *Essays in Transportation Economics and Policy*, J. Gomez-Ibanez, W. B. Tye, and C. Winston, eds. Washington: Brookings Institution Press.

Wheaton, William C. 1977. "Residential Decentralization, Land Rents, and the Benefits of Urban Transportation Investment," *The American Economic Review*, 67, 138-143.

CHAPTER 1

Literature Review

I review several strands of literature that are relevant to economic development impacts of highways and their redistribution effects in this chapter. First, I revisit the public capital literature, in which the debate on the productivity of public capital evolved over the past decade. Due to a great deal of attention given to the debate, this body literature is rich with insights on econometric methodologies, but has not yielded any conclusive policy recommendations. Then, I review the literature that attempts to reconcile the inconsistent findings in the public capital research, focusing on an emerging group of studies, which I call economic spillovers literature. In this literature, the spatial aspect of the public capital productivity question was investigated. Since the research on economic spillovers is relatively new, theoretical and methodological tools for studying the problem have yet to be fully developed. I turn to the literature on interjurisdictional tax and infrastructural competition, which has been examined more extensively on the theoretical side. The insights from each strand of literature will be used to develop a theoretical model and design an empirical study for examining economic impacts of highways in the subsequent chapters.

1.1. Aggregate Production Function Studies

The question of whether there is a shortage in public infrastructure investment has been subject to extensive investigation. Highway investment is of particular interest because it represents a large portion of infrastructure provided by the public sector. To answer this question, Aschauer (1989) adopted a framework of aggregate production function, which included public capital stocks as a part of the function, in addition to private factors of labor and private capital. His modified Cobb-Douglas production function is shown in the following equation:

$$Q = AK^{a}L^{b}G^{c}e^{\varepsilon} \tag{1.1}$$

where Q = output, A = technology level, K = private capital stock, L = labor, G = public capital stock, and ε = an error term.

Taking log of equation (1) yield:

$$\ln Q = \ln A + a\ln K + b\ln L + c\ln G + \varepsilon \tag{1.2}$$

Each coefficient can be interpreted as output elasticity respective to each input. Using time series regressions with data on private sector's output, private inputs, and public infrastructure stocks, Aschauer found a strong relationship between national productivity and public inputs. His estimates of output elasticity with respect to public capital ranged from 0.38 to 0.56. Given the existing public capital stock and output level, this estimate of output elasticity implies very high marginal product of public capital. This result led Aschauer to conclude that the decline in productivity in the U.S. beginning in the 1970s could be explained by the slowdown in public capital investment.

Aschauer's proposition was very provocative and stimulated a large amount of work in public infrastructure research. His aggregate production function framework became almost a standard tool for analyzing public capital productivity. However, Aschauer's econometric results also spawned much criticism – perhaps the most serious one is on unrealistic return to public capital investment. Using numerical illustration, many researchers pointed out that such estimates of output elasticity as provided by Aschauer implied unrealistically high marginal productivity of public capital - so high that it exceeded marginal productivity of private inputs (e.g. Aaron, 1990; Gramlich

1994). Various methodological problems have been cited as the source of the problem. Many researchers responded by employing more rigorous econometric techniques to create a large body of literature on this topic. The results of the subsequent research, however, are mixed, although it is generally agreed that Aschauer's original estimate of production elasticity of public capital is somewhat exaggerated.

The most important shortcoming of Aschauer's work is probably his reliance on aggregate time series regressions, which raised concerns that they may be dominated by common trends. The nonstationarity in time series can lead to a spurious correlation between output and public capital. Douglas Holtz-Eakin (1994), for example, noted that all postwar macroeconomic time-series data share a common characteristic shape. The productivity slowdown in the late 1970s may have less to do with the decline in investment on public capital stocks than with the energy crisis that occurred in during that time. In addition, the decline in public capital investment may reflect the tapering-out of expenditure on the Interstate Highway System, which was nearing its completion during that period. For theoretical discussions about spurious correlation, see Boarnet (1997) and Stock and Winston (1988).

There are several treatments that can help overcome the problem of spurious correlation. First of all, one can take the first difference of the time-series data to eliminate the common trends. This can be done by modifying equation (1.2) as follows:

$$\ln Q_t - \ln Q_{t-1} = \ln A_t - \ln A_{t-1} + a[\ln K_t - \ln K_{t-1}]$$

$$+ b[\ln L_t - \ln L_{t-1}] + c[\ln G_t - \ln G_{t-1}] + \varepsilon_t - \varepsilon_{t-1} \qquad (1.3)$$

Several authors (Hulten and Schwab, 1991; Aaron, 1990; Tatom, 1991; Kelejian and Robinson, 1994; Garcia-Mila, et al., 1996; Harmatuck, 1996) employed this technique and found much smaller, negative, or statistically insignificant contribution of public capital investment on private sector's productivity. Munnell (1992), however, argued that first differencing the time-series data might destroy long term relationship between the two variables. She suggested that instead of being tested for only non-stationarity, the data should also be tested for cointegration, i.e. whether the data series grow over time and converge to their long-run relationship. With this concern in mind, Holtz-Eakin and Schwartz (1995) noted that since highway stocks grow slowly, short-term observations, such as first differenced data, may produce gibberish results, and suggested "long differencing," i.e. subtracting equation for the initial year instead of the previous period in equation (1.2). This method is discussed in detail in section 1.4 of this chapter.

Another way to deal with spurious correlation is to substitute the aggregate time-series data with a more disaggregate panel data. The use of pooled-time series cross-sectional data provide more variation in the variables than relying only on aggregate time series, resulting in more efficient estimation. (Gramlich, 1994) This model specification can be expressed as follows:

$$\ln Q_{st} = \ln A_{st} + a \ln K_{st} + b \ln L_{st} + c \ln G_{st} + \varepsilon_{st} \qquad (1.4)$$

where the subscripts s and t index unit of observation, such as state or metropolitan areas, and time, respectively. Many authors employed this technique, notably Munnell (1990) who constructed a data set of state-by-state public and private capital stocks for 48 contiguous states from 1970 to 1986. Using this data set, she estimated the Cobb-Douglas production function as shown in equation (4) with three different assumptions about returns to scale: (1) no restrictions, (2) constant returns over the private inputs, and (3) constant returns over all three inputs. She found the estimate of productivity elasticity to be significantly positive regardless of the assumption used, but with substantially lower magnitude than the Aschauer's estimate (0.08 to 0.15 vs. 0.38 to 0.56). Other authors who used panel data sets (state or metropolitan level) found similarly less dramatic, or in some cases insignificant, contribution of public capital on productivity (Garcia-Mila and McGuire, 1992; Duffy-Deno and Eberts, 1991).

Douglas Holtz-Eakin (1994) raised another concern over the specification of production function in previous state-level studies. He argued that wealthier and more productive states tend to spend more on public infrastructure. For this reason, he believed that such underlying differences among states, which are unobserved in previous state-level production function studies, can greatly affect productivity, and consequently their results were plagued with a problem of missing variable. To correct this problem, he suggested a specification that controls for time-invariant, state-specific characteristics as well as the time trend (business cycle). These effects are unobserved and thus not considered in the previous literature. The improved specification of the error term is shown as follow:

$$\varepsilon_{st} = f_s + \gamma_t + \mu_{st} \qquad (1.5)$$

where the first term on the right hand side is a fixed-effect by state, the second is a fixed-effect by time, and the third is an i.i.d. error term. Holtz-Eakin used a panel data set from 1969 to 1988 to estimate the state-level production function. His fixed-effect estimation results revealed no signifcant contribution of public capital stock on state-level productivity.

Other researchers who employed fixed-effect estimation technique found similar results that productivity impacts of public capital disappear after unobserved characteristics of states are controlled (Garcia-Mila, McGuire, and Porter, 1996; Kelejian and Robinson, 1994). Garcia-Mila, et al. (1996), in particular, argued that even though the use of panel data is less prone to spurious correlation than the aggregate time series, a formal test showed that the nonstationarity problem still existed in the state-by-state data set, as constructed by Munnell (1990). This necessitates the first differencing of the panel data. In addition, they employed systematic search for the appropriate model structure and found that fixed state effect specification is superior to others. Unlike most previous authors, Garcia-Mila, et al. also broke down the public capital into three groups, namely, highway, water and sewers, and others. Their first-differenced fixed-effect estimation revealed insignificant role in each component of public infrastructure.

Andrews and Swanson (1995) also paid special attention to the issue of underlying differences in productivity specific to states. Unlike the previous authors, however, they determined random effect model to be superior to the fixed effect one. Using state-level data from 1970 to 1986, they reported an estimate of productivity elasticity of public capital of 0.11, well below the number reported by Aschauer and previous state level studies. They also argued that Cobb-Douglas production function, as commonly used in the literature, places too severe restrictions on production technology, and a more general functional form is needed. Therefore, they adopted the framework of translog production function, as shown below:

$$\ln Q = A + \sum_{i=1}^{3} \beta_i (\ln X - \ln \overline{X}) + \sum_{i=4}^{6} \beta_i (\ln X - \ln \overline{X})^2$$

$$+ \sum_{i=7}^{9} \beta_i (\ln X - \ln \overline{X})(\ln Y - \ln \overline{Y}), \; X \neq Y \qquad (1.6)$$

where X and Y are inputs of the production function, which include labor, private capital and public capital. Andrew and Swanson estimated the translog production function, using fixed effect specification, which yielded even smaller elasticity (0.04) at a 90% level of significance.

Lastly, many researchers have questioned the endogeneity problem in the aggregate production function that includes public capital (Eberts and Fogarty, 1997, Garcia-Mila and McGuire, 1992, Holtz-Eakin, 1994). They argued that while investment on public capital stocks may increase productivity, output growth can also cause expansion in public capital investment. The direction of causality is therefore unclear. Flores de Frutos and Pereira (1993) determined public capital to be endogenous, but still found significant contributions of public capital on output. On the other hand, Holtz-Eakin (1994) and Kelejian and Robinson (1994), who used instrumental variable technique to address the endogeneity problem, found insignificant role of public capital in productivity. More recently, however, Fernald (1999) reported a different result regarding endogeneity. To answer the causation question, he grouped various industries by their vehicle stock – relating this to how intensive the industry uses highways, and examined how changes in highway stock affect each group. Using inputs and outputs data for 29 sectors for the years 1953-1989, he found that industrial sectors that are more highway-intensive benefit more from increase in highway stock, and therefore concluded that the causality runs from highway stock to productivity. Additionally, in his earlier work (Fernald, 1993), in which disaggregate data by industry was also used, he found significant role of public highway in productivity.

1.2 Aggregate Cost Function Studies

Despite the popularity of the aggregate production function framework, there are many criticisms on its usefulness. Gramlich (1994), for example, criticized the excessive attention among researchers on the details of aggregate production function estimation, arguing that the approach is not appropriate for answering policy questions regarding the sufficiency of public capital investment. Friedlaender (1990) argued that production function, as a stand alone, is subject to a serious problem of misspecification, due to the treatment of factor prices as exogenous to the model. Since relative factor prices could influence the intensity of a firm's utilization of each factor, ignoring them would lead to biases in production technology coefficient. She proposed a total cost function framework as an alternative approach to aggregate production function studies in analyzing public capital productivity. The total cost function framework is less likely to suffer from the misspecification problem because all relevant variables enter the total cost function as given by:

$$C = C^v(Q, w, r, G, t) + \gamma G \tag{1.7}$$

where C = total cost function, C^v = variable cost function, Q = output, w = wage rate, r = private capital rent, t = time trend to capture technology change, G = public capital, and γ = opportunity cost of public capital.

From this equation, she derived the shadow price of public capital, defined by the total cost savings that would result from a unit increase in public capital

$$\rho = \frac{\partial C^v(\cdot)}{\partial G}. \tag{1.8}$$

Friedlaender suggested that one can judge whether the current level of public capital is optimal by comparing its shadow price (ρ) with its opportunity cost (γ) in equilibrium, which can be expressed as

$$\gamma = -\frac{\partial C^{*}(\cdot)}{\partial G^{*}}. \tag{1.9}$$

where G^{*} represents the equilibrium level of public capital. If the shadow price is greater than the opportunity cost, the public capital is underprovided and vice versa. Friedlaender acknowledged the difficulty in obtaining data for the estimation of the regional cost function, but she was optimistic that the information could be gathered from various sources.

Several researchers adopted the cost function framework to examine the productivity impact of public capital. Nadiri and Mamuneas (1994), for example, applied Friedlaender's idea to examine the impact of public capital on aggregate cost function of twelve manufacturing industries at the national level. They reasoned that an increase (or improved quality) in public capital can influenced production costs in two ways: (1) it will shift the cost function curve downward, and (2) it will affect how firms choose the level of each input. The first effect represents the direct benefit from public capital, which may vary among industrial sector, as argued by Fernald (1993, 1999). The second effect represents how public capital influences firms' input decision, depending on whether public capital is a complement or a substitute of each type of input. They estimated average cost functions in a translog form that take two types of publicly-financed capital, i.e., infrastructure and research and development (R&D). The average cost function is given by

$$\ln(C_h / P_{mh}) - \ln y_h = \beta_{0h} + \sum_i \beta_{ih} \ln w_{ih} + \beta_{th} t + \sum_{i \neq j} \sum_j \beta_{ijh} \ln w_{ih} \ln w_{jh}$$

$$+ \sum_i \beta_{ith} \ln w_{ih} t + \sum_s \phi_{sh} \ln S_{sh} + \sum_s \sum_i \phi_{ish} \ln w_{ih} \ln S_{sh} . \tag{1.10}$$

where C_h is a cost function in industry h; w_{ih} is the price of factor i (the subscript i and j represent labor and private capital); y_h is the output; S_{sh} is the public capital (the subscript s represent infrastructure and R&D). Using the data from various sources, e.g. the Bureau of Labor Statistics (BLS) and previous authors such as Alicia Munnell, they estimated this cost function with a one-year lag of public capital to account for the possibility of delayed effect. They found that the effect of public capital on the cost structure is significant, i.e., it reduces cost in each manufacturing industry. However, the effects of public capital vary greatly among different industrial sectors, with the magnitudes of the cost elasticities ranging from –0.11 to –0.21.

Morrison and Schwartz (1996) examined the impact of the three key public infrastructure, highways, water, and sewers, on manufacturing industries costs. They estimated the variable cost function, using a generalized Leontief (GL) specification, given by

$$G(\bar{x}, \bar{P}, t, Y) = Y\left[\sum_i \sum_j \alpha_{ij} P_i^{0.5} P_j^{0.5} + \sum_i \sum_m \delta_{im} P_i s_m^{0.5} + \sum_i P_i \sum_m \sum_n \gamma_{mn} s_m^{0.5} s_n^{0.5}\right]$$

$$+ Y^{0.5}\left[\sum_i \sum_k \delta_{ik} P_i x_k^{0.5} + \sum_i P_i \sum_m \sum_k \gamma_{mk} s_m^{0.5} x_k^{0.5}\right] + \sum_i P_i \sum_k \sum_l \gamma_{lk} x_k^{0.5} x_l^{0.5} . \tag{1.11}$$

where G is the variable cost function; t represents time trend; Y is the output, x_k and x_l are the quasi-fixed inputs; P_i and P_j are variable input prices; and s_m and s_n denote the t and Y. This GL functional form allows for flexible technological and behavioral adjustments of firms, and thus is more desirable than restricted functions, such as the Cobb-Douglas, conventionally used in the literature. Using annual data on input prices and output quantity in the manufacturing industries for the years 1970-1987, the authors estimated the cost functions, input demand functions, short run marginal cost functions by the U.S. region, namely, Northeast, North Central, South, and West. Like Holtz-Eakin (1994), they used state-level data, and employed the fixed effects estimation technique, with state-specific dummy variables. In addition, by using alternative instrumental variable specifications to address the endogeneity issue, they also determined that endogeneity is not a serious problem. Their results, however, are contrast to those of Holtz-Eakin, who found no significant role of public capital in influencing output when unobserved state-specific traits are controlled. Morrison and Schwartz found public infrastructure to have significant impacts on reducing costs in manufacturing industries, even after accounting for states' unobserved characteristics. They attributed this difference to the fact that the production function and cost function frameworks are not equivalent, contending that "our cost-function approach brings an additional dimension into the analysis by incorporating behavioral responses and also accommodates interactions among inputs through the flexibility of the functional form, both of which are bypassed in the simple production function specification used by Holtz-Eakin."

1.3 Reconciling the Differences: Spatial Considerations

The large body of public capital literature has produced no conclusive results – the issue of public capital productivity remains unresolved. Many researchers dismissed the significant contribution of public capital to private sector productivity as the relics of careless econometric studies (e.g. Tatom, 1991; Holtz-Eakin, 1994; Kelejian and Robinson, 1997). Nonetheless, other researchers, who applied sophisticated econometric techniques, did not fail to reveal the significant role of public capital (e.g. Flores de Frutos and Perreira, 1993; Fernald, 1993 and 1999; Nadiri and Mamuneas, 1994; Morrison and Schwartz, 1996). Can these conflicting findings be reconciled?

Recently, a new line of reasoning that may offer a possibility of reconciliation has emerged. Many researchers began to realize that spatial considerations are critical for public capital productivity analysis. This is quite intuitive since even the most superficial observation would reveal that public capital investment has disparate impacts over space. For example, a new highway project may stimulate the whole regional economy during the construction, but upon completion, the areas that benefit most would likely be those near highway interchanges and ramps where most economic activities take place. In fact, the highway might have adverse impacts on some areas. For instance, those areas near the highway but distant from the ramps would experience air and noise pollution, but would not greatly benefit from increased economic activities. Remote and rural areas may also be hurt if the business activities relocate from those areas to the highway corridor. As can be seen in this example, depending on the scale of analysis, public capital contributions to regional economic performance can range from very productive (near highway interchanges) to neutral (at the regional level where positive and negative impact canceled out) to negative (remote areas not served by the highway). Spatial considerations are therefore crucial in analyzing the productivity impact of public capital. Unfortunately, despite the potential insights that can be gained from analyzing the problem in this way, not until recently have researchers formally designed their studies to examine the spatial effects of public capital productivity.

A major contributor to public capital debate, Alicia Munnell, is among the first to recognize the importance of spatial considerations in public capital research. In her 1992 paper, she surveyed the literature at the time, and compiled a table that listed estimates of output elasticities of public capital at different geographic level. She noted that the elasticities are very similar at the same geographic level, with larger estimates corresponding to higher level of aggregation. For example, national output elasticities estimates ranged from 0.34 to 0.39, state estimates from 0.15 to 0.20, and metropolitan estimates from 0.03 to 0.08. She attributed the variation of elasticity estimates according to geographic scale to the so-called "leakages" of economic benefits from smaller geographic units, which accumulate to greater value at the larger scale. Although it will be shown later that Munnell's rationale is not entirely correct, this observation led the way to more empirical investigations of the economic leakages, later to be better known as economic spillovers.

Inspired by Munnell's leakages hypothesis, the first wave of research, which from now on I will call economic spillover literature, is an extension of the state-level panel studies (Holtz-Eakin, 1994; Holtz-Eakin and Schwartz, 1995; Kelejian and Robinson, 1997). Researchers of this type of studies often found the evidence to reject the spillover hypothesis, i.e. productivity of any given state is not influenced by public capital stock of its neighboring states, with a notable exception of Andrew and Swanson (1995). Later, the second wave of research involved more geographic detailed analyses (Rephann and Isserman, 1994; Boarnet, 1998; Chandra and Thompson, 2000). Utilizing county-level panel data, these authors consistently found significant economic spillovers of highways. The consistency of their findings is remarkable, given the widely publicized controversy surrounding public capital research. I review both groups of literature in the following section.

1.4. Economic Spillover Literature

The first group of economic spillover research extended the state-level panel studies by introducing spatial interactions into the production functions. Holtz-Eakin and Schwartz (1995) tested Munnell's positive spillovers hypothesis by including the "effective," rather than the actual, stock of highways of each state in the usual log-linear production function, reasoning that highway provision in other states may also contribute to a given state's productivity. They defined the effective highway stock as follows:

$$h_{se} = h_s + \delta \sum_{n=1}^{N_s} w_n h_{ne} = P(\delta)H \tag{1.12}$$

where h_{se} is the effective highway stock; h_s is the actual highway stock; δ is the spillover coefficient; w_n is the weight associated with how strongly the spillover from state n might be; h_{ne} is the actual highway stock in state n; and H is a vector of highway stocks for the states.

To estimate the production function, Holtz-Eakin and Schwartz used state-level data provided by Munnell (1990) and the Bureau of Economic Analysis (BEA). They also paid special attention to Munnell's argument that first-differencing the data would obscure the long-run effect of public capital on output, and suggested an alternative method to deal with trend-dominated time series, called "long-differencing." This method involved the subtraction of the production function equation for all time periods by that of a given "initial" time period.

$$y_t - y_0 = \beta_1(l_t - l_0) + \beta_2(k_t - k_0) + \beta_3 P(\delta)(H_t - H_0) + (\gamma_t - \gamma_0) + (\mu_t - \mu_0) \tag{1.13}$$

where y is output; l is labor, k is private capital; γ is time-specific intercept; and μ is i.i.d. normal errror term. Note that the state specific time-invariant intercepts are cancelled out.

Since the resulting error terms will be serially correlated, the coefficient estimates will be inefficient. The authors also suggested the use of covariance matrix of the error terms, which is given by:

$$E(\mu_{st} - \mu_{s0})(\mu_{sr} - \mu_{s0}) = 2\sigma^2, \text{if } t = r;$$
$$= \sigma^2, \text{ otherwise.}$$

for GLS to obtain efficient estimates of the coefficients. The estimation results show negative and significant coefficient of neighboring states' highway stock when the level variables are employed, but show no statistically significant impacts when the differenced variables are used.

Kelejian and Robinson (1997) expanded the state-level aggregate production function approach to explicitly consider spillovers, also using the panel data set constructed by Alicia Munnell. Their specification of the Cobb-Douglas production function is simplified as follows. (See the full version in Kelejian and Robinson, 1997.)

$$\ln Q_{it} = A + \beta_1 \ln L_{it} + \beta_2 \ln K_{it-1} + \beta_3 \ln P_{it-1} + \beta_4 \ln D_{it}$$

$$+ \beta_5 \ln \underline{P}_{it-1} + \beta_6 \ln \underline{PROD}_{it} + \beta_7 U_{it} + \beta_8 t + \varepsilon_{it} \qquad (1.14)$$

where Q_{it} is output of state i at time t; L is labor; K is private capital, P is public capital. Four productivity shifters include population density, D, public capital in neighboring states, $\underline{P}$, productivity (output per capita) of neighboring states, $\underline{PROD}$, and unemployment U. Kelejian and Robinson stated their a priori beliefs about spillover coefficients as follow. The sign of coefficient of neighboring states' public capital is ambiguous due to the confounding positive network effect and negative factor migration effect. The sign of neighboring state productivity should be unambiguously positive for two reasons. First, being close to highly productive states should spur competitive environment, encouraging the lagging state to catch up. Second, technological spillover from advanced states should have positive impact on neighboring states.

Kelejian and Robinson employed five variations of econometric techniques to estimate the production function, namely, (1) The basic model (equation (1.14)) with fixed state effects, (2) variation 1 with the error terms as AR(1) process, (3) variation 2 with endogenous cross-state production $\underline{PROD}$, (4) variation 3 with endogenous labor L and unemployment U, and (5) variation 4 with heteroscedastic error terms over states and time. Also, they considered the case where the error terms are spatially correlated. The estimations of five specifications yield quite consistent results about spillovers. The coefficients of production spillover are remarkably robust – they are always positive and statistically significant regardless of econometric specifications. The coefficients of public capital spillovers are almost always insignificant with inconsistent sign.

The second group of economic spillover research deals with more detailed-geographic level of analysis. Among the first reasearchers to conduct this type of studies are Rephann and Isserman (1994) who examined the spillover effects of highway investment at the county level. They utilized a quasi-experimental approach to compare "treated" counties with their "untreated" or "controlled" ones. The treated counties received a new highway, and they are expected to experience different economic growth patterns from the controlled counties, whose economic and spatial characteristics are used as the baseline for comparison. Using a matching method introduced by Campbell and Stanley (1963), the authors selected a controlled county for each treated county in such a way that the "twin" pair shared the most similar economic and spatial characteristics. After the controlled counties were chosen, the authors performed a "pretest" to ensure that the matches were good enough, by comparing the differences in growth rate of each twin pair before highway construction. They found few statistically significant differences, leading them to conclude that the twin pairs were appropriate for the quasi-experiment.

Adopting a regional taxonomy developed earlier by Rephann (1993), Rephann and Isserman examined spillovers in three types of rural county, namely, competitive, urban spillover, uncompetitive counties. Competitive counties are distant from metropolitan areas and contain medium-sized cities (with population over 25,000), which benefit directly from a new highway, as it increases their competitive advantages. Urban spillover counties are located near a metropolitan area, and also gain from a new highway, which induces urban decentralization from the neighboring highly urbanized region. Uncompetitive counties are mainly remote and rural regions, and gain little benefit from a new highway. In addition, the authors also investigated the spillover effects in adjacent counties, defined by those counties that are close to the treated counties, but located off the highway.

For each type of county, Rephann and Isserman computed the mean differences in growth rate of several variables, such as population, total earning, and earnings in various sectors, including retail trade, services, local and state government, etc. They documented and graphed the changes in these variables over time. The results are summarized in Table 1.1.

Table 1.1 Summary of Rephann and Isserman's (1994) Results

County type	Mean differences in growth rate of						
	Population	Residential Growth	Total Earnings	Retail Earnings	Manufacturing Earnings	Services Earnings	State & Local Gov't Earnings
Competitive	+	--	++	++	+/-	-/+	++
Urban Spillover	++	++	++	++	++	++	+
Uncompetitive	+	+/-	+	+	++	-	0
Adjacent	-	-	-/+	--	+	-	-

In competitive counties, treated counties' growth in total earning, retail earning, state and local government activities represents the greatest and significant positive deviation from those of controlled counties. The treated urban spillover counties experienced faster growth than the untreated counties in every variable, notably residential, manufacturing, retail, and services growth. This result might be expected from urban decentralization of residential and commercial sectors. The twin pairs in uncompetitive counties experience similar patterns of growth, but the growth rates in most sectors in treated counties are slightly higher. Lastly, but perhaps most importantly, growth rates in many variables, including population, government activities, retail, and services in the treated adjacent counties are statistically smaller than those in the controlled group. The differences in growth rates of other variables, however, are mainly statistically insignificant. The results provided additional evidence in support of negative spillovers hypothesis.

Invoking the spillover argument, Boarnet (1998) focused on cross-county economic impacts of highway stocks in California. He conjectured that negative spillovers should be strongest on other counties that are most "similar" or "substitutable", in terms of production location characteristics. This is so, he reasoned, because factor migration occurs more easily across areas that are close substitutes as production locations. For example, it would be easier for a firm that needs to hire from a large pool of labor to relocate from one highly urbanized area to another, but it may be difficult for them to relocate to a relatively remote and rural area. One of the characteristics that can be used to define county similarity is therefore the degree of urbanization, which may be proxied by population density.

In addition, Boarnet also argued that positive spillovers should be most pronounced on contiguous counties that are connected by the same highway network system. For example, if two contiguous counties are connected by several highways, a new highway in one county will significantly, if not equally, benefit the other county. On the other hand, if those two county are contiguous, but not connected by any highways, then a new highway in one county will only benefit that county, but produce little gain, if at all, in the other county.

Following Holtz-Eakin and Schwartz (1995), Boarnet estimated the long-differenced log-linear production functions, using county level data from 1969 to 1988. The differenced production function equation is given by

$$\ln Q_t - \ln Q_0 = \alpha_1[\ln L_t - \ln L_0] + \alpha_2[\ln K_t - \ln K_0] + \alpha_3[\ln \mathbf{H}_t - \ln \mathbf{H}_0]$$
$$+ \alpha_4[\ln \mathbf{WH}_t - \ln \mathbf{WH}_0] + \gamma_t - \gamma_0 + \varepsilon_t - \varepsilon_0 \qquad (1.15)$$

where Q is county output, L is employment, K is private capital stock, $\mathbf{H}$ is a vector of highway stock, and $\mathbf{W}$ is a matrix that defines neighboring relationship. The county subscripts are suppressed in the equation. County fixed effects are canceled out from the differencing. Time specific effects and i.i.d. error terms remain at the end of the RHS of equation (1.15).

To test the negative spillovers hypothesis, Boarnet defined "similar" counties in many different ways, according to counties' socioeconomic characteristics, including population density, per capita income, and employment in services and manufacturing sectors. These proxies of county "similarity" enter the equation in the form of the weight matrix, **W**, whose elements are defined as follow:

$$w_{i,j} = \frac{1/|X_i - X_j|}{S_i}$$

where $S_i = \sum_j 1/|X_i - X_j|$;

X_i is the proxy of county similarity. For example, $\mathbf{W}_{pden}$ was constructed by substituting population density into *X's* in the weight equation above. Similarly, $\mathbf{W}_{inc}$, $\mathbf{W}_{FIRE}$, and $\mathbf{W}_{manu}$ were constructed, using per capita income, FIRE and manufacturing sector employment respectively. As can be seen, the more similar a pair of counties in terms of these proxies, the greater the weight corresponding to that pair.

The positive spillovers hypothesis was tested by defining the weight matrix to reflect connectivity of highway network, $\mathbf{W}_{net}$, whose elements are given by

$$w_{i,j} = \frac{N_{i,j}}{\sum_j N_{i,j}}$$

where $N_{i,j}$ is the number of highways connecting contiguous counties i and j. Again, the higher the number of common connecting highways, the greater the weight of a county pair.

The weight matrices (**W**) were multiplied by the highway stock vector (**H**). The resulting vector (**WH**) enters the production function equation (1.15). The coefficient of this variable and its sign reflect the spillovers from other counties. At a given level of highway stock, a more similar pair of counties (higher weight) will experience stronger spillover effects than a less similar pair (lower weight).

The estimation results showed that highways' own-county output elasticity, α_3, is statistically significant in various specifications. More importantly, the results also supported the spillovers hypothesis, revealing statistically significant coefficients of cross-county highway capital (α_4), with magnitude and sign depending on various definitions of **W**. When the weight was defined to capture network effect of highway ($\mathbf{W}_{net}$), the coefficient was significantly positive, reflecting the positive spillovers of highway stock in one county to contiguous counties connected by the same highways. The coefficient became significantly negative when the weights were defined to reflect substitutability among the counties ($\mathbf{W}_{pden}$ $\mathbf{W}_{inc}$, and $\mathbf{W}_{FIRE}$), supporting the negative spillovers hypothesis, i.e., highways stocks in a county negatively affect counties with similar characteristics in terms of population density, per capita income, and type of employment.

Chandra and Thompson (2000) investigated the spillovers in non-metropolitan counties, by tracking the effects across industrial sectors and time. In their theoretical spatial competition model, the private sector firms are divided into two groups. Firms in the first group produce goods or services that are traded regionally, while those in the second group nationally. The model predicts that an introduction of a new highway in a region will cause firms with regionally traded goods to contract if they produced at high costs, and expand otherwise. This type of firms, including retail and services firms, is likely to contract, unless they produce at very low costs. On the other hand, firms with nationally traded goods, like manufacturing firms, will unambiguously expand, following the introduction of a new highway.

To account for differential impacts across industries, Chandra and Thompson estimated separate equations for each single digit SIC group industry, using county, state and national level data available for year 1969 to 1993 from the U.S. Department of Commerce's Regional Economic Information System. The equation's dependent variable is the natural log of earnings by industry, and the explanatory variables include age of highways, industry-specific state and national business cycle, time-invariant county fixed effects as given by:

$$\ln y_{it} = \alpha + X\beta + \eta \ln STATE_t + \gamma \ln US_t + \mu_i + \upsilon_{it} \tag{1.16}$$

where y_{it} is earnings by industry, X is a matrix of highway ages, $STATE_t$ is the state-level earnings in non-metropolitan areas, US_t is the national earnings, μ_{it} is a time invariant-county fixed effect, and v_{it} is the i.i.d. disturbance. Chandra and Thompson argued that the advantage of using the matrix of highway ages is that the resulting model is non-parametric by nature, so there are no severe restrictions in functional form. The loss of degree of freedom is not a problem because of a large sample size. The authors also examined the possible impacts on earning prior to the opening of a new highway by allowing the age variable to take negative values up to 5 years in the highway age matrix X.

To examine the spillover effects, Chandra and Thompson divided counties into two groups, highway and adjacent counties, and estimated three models, for pooled, highway, and adjacent counties. In this way, they interpreted the pooled model coefficients as the net regional impacts of highways, and those of highway and adjacent counties as spatial relocation of economic activities within the region, reflecting spillovers from highway counties to adjacent ones.

The regression results of Chandra and Thompson (2000) are summarized schematically in Table 1.2.

Table 1.2 Summary of Chandra and Thompson's (2000) results

	Sector				
County	Manufacturing Earnings	Retail Earnings	Services Earnings	TCPU	Total Earnings
Pooled	+	+/-	+/-	+/-	+/-
Highway	+	+	+	+	+
Adjacent	+	-	-	-	-

As can be seen, a new highway tends to increase earnings in manufacturing sector in all three regressions. This result falls in line with the prediction of the theoretical model that sectors with nationally traded products will benefit from a new highway. On the other hand, earnings in retail, services, and TCPU (Transportation, Communications, and Public Utilities) sectors, also tend to increase in highway counties, but decline in adjacent counties. As a result, the net earnings in the pooled regressions are ambiguous. The total earnings also follow the same pattern, revealing the fact that the increase in manufacturing earnings is offset by the decline in earnings in other sectors. These results are also consistent with the prediction of the theoretical model that the sectors with regionally traded products may experience increased or decreased earnings from an opening of a new highway. The overall results support the hypothesis that highways exert differential impacts across industrial sectors. They also provide additional the evidence that new highways in one area can cause negative spillovers on other neighboring areas, and that the migration of private factors and the relocation of economic activities to locations near highways are a real and significant phenomenon.

1.5 Lessons from the Economic Spillover Literature

The review of the economic spillover literature highlights the importance of spatial considerations in public capital research. That the aggregate studies, i.e., the national and state-level studies, often reveals no role of public capital does not necessarily imply that public capital produces no economic benefits. As shown in the disaggregate studies, public capital, particularly highways, may be productive at the highly localized level – counties that receive highway investments experience faster growth in various key economic variables. However, the literature also showed that Munnell's hypothesis of positive economic spillovers is not entirely accurate. Both positive and negative spillovers exist at the detailed-geographic level, and negative impacts are often times dominant. As a result, when spillovers are measured at higher aggregation level, the two opposing effects are likely to confound the results. This is a plausible explanation for failure to uncover economic spillovers of public capital in the state-level studies.

In addition to providing a potential reconciling ground for the public capital productivity puzzle, the economic spillover literature also offers many other useful lessons, including both theoretical insights and methodologies to approach the problem. These lessons are summarized below.

Private Factor Growth and Negative Spillovers: Two sides of the Same Coin

When public capital is provided, two intertwined economic impacts can be anticipated, namely *productivity benefits* and *factor migration*. These impacts vary over geographic space. Consider first the place where the public capital is provided – I call this an *impact area.* Assuming that public capital is strictly locally productive, the impact area experiences enhanced economic performance, due to the productivity of the capital, and therefore become a more desirable place for doing business. A new highway, for example, reduces travel time and distribution costs of firms located along the highway corridors. The improvements in travel time may encourage firms to adopt a more transportation-intensive production process, referred to as industrial reorganization by Mohring. Improved productivity may result from innovations in production technology, ed it, industrial reorganization, or simply the fall in production costs. I call this type of benefits, *productivity benefits.* As far as the public capital literature goes, these benefits are capitalized into higher land and factor prices, and the story ends there.

The spillover argument pushes this discussion further. Productivity benefits in the impact area improve its competitive advantage and factor prices. Private capital and labor from elsewhere may migrate into the impact area where factor prices are higher, due to the higher productivity. In addition, rather than locating elsewhere, new firms may choose their locations within the impact area, bringing in even more private production factors. I call the benefits from factor growth that is induced by public capital investment in the impact area, *factor in-migration benefits.* Both productivity and factor in-migration benefits contribute to output growth in the impact area.

At the same time as public capital, through enhanced productivity, attracts private factors into the impact area, places elsewhere suffer collectively from factor out-migration or lose what would have been located there. I consider the loss in private factor endowment that occurred to places outside the impact area *negative spillovers.*

Undoubtedly, the benefits of public capital investment experienced in the impact area come, at least partially, at the cost of places elsewhere. Factor in-migration benefits in the impact area on the one hand and factor out-migration or losses of potential private investment elsewhere on the other are in fact two sides of the same coin. This has some critical policy implications. For instance, decentralized public capital investment decisions may not be socially optimal because local provider may not take into considerations the adverse impact of the investment on other areas.

Positive Spillovers

Public capital investments may also create positive spillovers, depending on the type of public capital. First and most important to this research, public capital in the form of transportation infrastructure has a network characteristic. Adding a new link into a network of highways benefits not only places along the link, but the entire area that is served by the network because the additional link creates connectivity among a greater number of origins and destinations. However, the magnitude of this type of positive spillovers depends on the density and size of network. In a newly developed network, such as the early stage of the U.S. Interstate Highway System, the external network benefit may be great. At mature stage, as it is at this point in time, adding more highway links to the system may provide little positive spillovers, but rather cause more negative spillovers as discussed earlier.

Other forms of public capital investment may also create positive spillovers. Investment on education and R&D, for example, may have far-reaching benefits, such as increasing the high-quality labor pool and knowledge and technological spillovers. Also, a highly productive region may encourage other regions to catch up by attempting to become more efficient. Transportation infrastructure does not seem to exhibit these types of positive spillovers, which will therefore not be focused in this research.

Impact Areas and Unit of Analysis

Essential to economic impact assessments of public capital investment is how an impact area is defined. A critical implication of spillover argument is that the smaller impact area, the more significant positive economic impacts. As mentioned earlier, in a larger impact area, negative spillovers cancel out the positive impacts, and therefore overall economic impacts are likely to be minimal. This is evident in the literature where results from the state-level studies contrasted with the unequivocally significant negative spillovers in the county-level studies. Unfortunately, to my knowledge, the county-level analysis is the lowest level of aggregation for this type of research. There is much left to be desired in terms of policy relevance. For example, the county-level studies focus mostly on rural counties, with the exception of Boarnet (1998) who did not differentiate rural and urban California counties. They cannot provide policy insights when it comes to highly urbanized areas. A large metropolitan area tends to consist of numerous local jurisdictions, which make public investment decisions by themselves. Factor migration, induced by public investment, is most likely to take place among these local jurisdictions. These local jurisdictions, cities and towns, may also differ greatly in terms of existing socio-economic and demographic characteristics, taxing policy, zoning regulations, all of which can affect factor migrations. Therefore, it is very important to have a highly disaggregate analysis of economic impacts so that the best policy recommendations regarding critical issues, such as allocation of funding responsibilities and interjurisdictional competition of infrastructure provision, can be made.

Sectoral Considerations

In addition to spatial considerations, the literature also showed that economic spillovers vary by industrial sectors. For instance, the spillover effects of transportation infrastructure depend on the market of firms' output. Firms with locally traded output, such as those in retail and services sectors are most likely to suffer serious negative spillovers. In the manufacturing sector, firms' products tend to be marketed regionally or nationally. Thus, they may experience insignificant negative spillovers, and in many cases, benefit from transportation investment in distant areas that open up potential markets. Since in general the economy has evolved to become more service-oriented, negative spillovers are important for the economic assessment of transportation projects.

Temporal Considerations

The economic spillovers from public capital investment do not occur overnight, they evolve over time. Investors' foresight may play an important role as they may speculate that public investment will be made in a certain area and buy the land. After the project is finished, it may also take some time for the productivity benefits to signal investors to relocate factors there. Clearly, a cross section analysis at a certain point in time is not adequate for analysis of economic spillover.

Measurement of Spillovers

Three types of variables are used to measure spillovers in the literature, regional outputs (state-level studies and Boarnet, 1998), earnings by industrial sectors, and level of factors, such as employment. The use of the first two types of variable to measure economic growth in an impact area may be problematic because the productivity and factor in-migration benefits can not be distinguished. To isolate factor migration effects, the level of factors should be used. However, the data on private production factors, such as private capital, are usually not available at the highly detailed geographic level. Hence, the researchers had to make do with outputs or earnings data, despite their problems.

Lack of Theoretical Modeling

The literature offers mostly empirical evidence, with little attempt to theoretically clarify the process of economic spillovers through factor migration. Boarnet's work is probably the most theoretically advanced since he distinguished between negative and positive spillovers, and identified factor migration as the major cause of negative spillovers. More research effort is needed to develop better theoretical understanding of the process of factor migration, due to public investments. Fortunately, there is a parallel field of economic research that is more theoretically developed, namely, the interjurisdictional tax competition literature, which focuses on the impact of taxing policy on the movement of private factor. In the next section, I review this body of literature to obtain some modeling strategies.

1.6. Interjurisdictional Tax Competition Literature

In the tax competition literature, researchers studied the movement of private factors in response to local governments' taxing behavior. A key assumption of most models is that private capital is perfectly mobile among local jurisdictions. Therefore, in setting tax rates, a local government must consider how it will affect capital movement.

Basic assumptions

Aside from perfect capital mobility, several basic assumptions are standard in most tax competition models. In a simple model, an economy consists of two or more regions, with identical aggregate production functions, which take two inputs, labor and capital. The production function is generally assumed to be homogeneous of degree one in inputs, twice differentiable, and quasi-concave in inputs. Also, the production function is often assumed to be of Cobb-Douglas form with constant returns to scale, as this satisfies all of the usual properties above.

Each region has its own government, which sets a capital-tax rate. The governments use only capital-tax revenue to finance public service, and no other tax instruments. In simpler models, only private-sector production is considered. More complicated models also incorporate a residential sector, with some allowing households to move among the regions. In this case, the governments attempt to maximize household utility, which depends on private consumption and public service provided by the governments.

The Problem

A local government is faced with a dilemma when it sets the capital tax rate: it must set the tax high enough to raise sufficient funds to cover the costs of public service, and at the same time, it cannot set the tax too high or the capital will move somewhere else. Since other governments' tax policies also affect capital migration, local governments play an economic game. In most studies, the Nash solution is examined, and compared to the social optimality, i.e., whether the Samuelson's condition is met.

Private Factors Migration in Response of Tax

The choice of tax rate affects factor prices, and consequently firms' utilization of each factor. When capital is mobile, a distortionary capital tax[1] induces migration in response to its payment. In the literature, factor migration is analyzed in the context of how tax distorts factor prices. First, consider the case where there is no tax. In equilibrium, a production firm will hire capital up to the point where a unit of capital is paid its marginal revenue product. Assuming the unit price of the output is one, we have:

$MP_k = r_o$

where MP_k is the marginal product of capital k; r is the capital rent payment.

In a two-region model, this condition holds for both regions, and with the same capital rent payment r_o. Now, if a tax rate of t is levied on capital in one region, then the equilibrium condition in the taxing region becomes:

$MP_k = r_I + t.$

Since the rent equality between the two regions must still hold, marginal product in the no-tax region equals r_I. Also, since MP_k is a decreasing function of k, and $r_I + t > r_I$, for this condition to be satisfied, the capital in the taxing region must migrate to the other region. The capital rent decreases in both regions. However, the taxing region suffers loss in the capital stock and therefore experience output shrinkage. The no-tax region on the other hand expands in terms of capital stock and output.

General Result

The general result from the tax competition literature is that, in Nash equilibrium, local governments, for fear the flight of valuable capital tax base, set the capital tax rate too low. Identical regions will *all* adopt suboptimal tax rate[2], leaving capital allocation undistorted, but will consequently *underprovide* public service.

Extensions

Many restrictive assumptions have been relaxed in the tax competition literature. I only briefly review those extensions that are relevant and potentially useful to this

---

[1] When the population is homogeneous, head tax is non-distortionary.

[2] The optimal capital-tax rate is set such that the Samuelson's condition of public goods is met.

research. Bucovetsky (1991) examined the case where regions are of uneven size. He found that the smaller region, which experience more elastic capital flight will keep the tax rate lower than the larger region. Wheaton (1995) built on Bucovetsky's model, and found that the relative sizes of the competing regions affect not only the extent of tax rate differentials, but also the impact on aggregate output. Lee (1997) studied the problem under the assumption of imperfectly mobile capital, using a two-period model. In the first period, capital is perfectly mobile, while it is costly to move capital in the second. He showed that the imperfect mobility of capital cause overly aggressive competition of local jurisdictions, which try to attract capital in the first period, resulting in overprovision, rather than underprovision, of public service.

In general, public services are used by both production and household sectors. However, in most studies, it is usually assumed that public service is used by household sector only, and the productivity of production sector depends only on factor endowments. In this case, households have an identical utility function, which depends on composite good, often used as a numeraire, and public service. Local governments set the tax rate to maximize households' utility subject to a budget constraint, which in turn is a function of tax revenue. Wildasin (1988) formulated the problem differently, i.e., rather than setting tax rate, the government balances fiscal budget for public expenditure to maximize household utility. He showed that the Nash equilibrium solutions of the two problems are not the same in general.

Haughwout (1998) did not research tax competition, but his study bears some resemblance in terms of methodology, and the results are quite interesting from this research perspective. He investigated how productive public capital influences overall output. His aggregate production function takes only land and labor as inputs, with public capital as productivity shifters. He showed that even though public capital is productive, its investment may not necessarily increase overall aggregate output. Also, he showed that some unproductive (zero marginal product) investment of public capital may increase output under certain conditions. This is so because the effect of public capital on relative input prices may induce firms to substitute public capital for private inputs in ways that have not been considered before in the literature. His model, however, is of a single economy, and does not address factor migration explicitly. Yet, the result serves as a caution that one must be careful not to overlook the importance of factor price effects when attempting to model the impact of public capital investment.

1.7 Summary

In this chapter, I review four strands of literature, the public-capital research with aggregate-production-function framework, the public-capital research with aggregate cost-function framework, the economic-spillover literature, and the interjursidictional tax-competition research. The first two strands of literature illustrate many pitfalls of researching the linkage between public capital investment and productivity, and provide cautions that many econometric problems are likely to arise in empirical studies. The third strand of literature provides an overview of the problem of economic spillovers and how it can be approached by a better understanding of the factor migration process as spillovers. Finally, the fourth strand of literature offers a theoretical framework, which the economic spillover research usually lacks, for the problem of factor migration in the context of interjurisdictional competition. I use this knowledge to create a basic theoretical model for this research in the next chapter, and design an empirical test in the subsequent chapter to shed more light on the question of economic spillovers of highway investment.

References

Aschauer, David A. 1989. "Is Public Infrastructure Productive?" Journal of Monetary Economics, 23, 177-200.

Aaron, Henry J. 1990. "Discussion," In Alicia H. Munnell (ed.), *Is There A Shortfall in Public Capital Investment?*, Proceedings of Federal Reserve Bank of Boston conference.

Andrews, Kim and Swanson, James. 1995. "Does Public Infrastructure Affect Regional Performance?" *Growth and Change*, 26, 204-216.

Boarnet, Marlon G. 1998. "Spillovers and the Locational Effects of Public Infrastructure," *Journal of Regional Science*, 38, 381-400.

Chandra, Amitabh and Thompson, Eric. 2000. "Does Public Infrastructure Affect Economic Activity? Evidence from the Rural Interstate Highway System," *Regional Science and Urban Economics*, 30, 457-490.

Evans, Paul and Karras, Georgios. 1994. "Are Government Activities Productive? Evidence from a Panel of U.S. States," *The Review of Economics and Statistics*, 76, 1-11.

Fernald, John G. 1999. "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity," *American Economic Review*, 89, 619-638.

Forkenbrock, David J. and Foster, Norman J. 1990. "Economic Benefits of a Corridor Highway Investment," *Transportation Research Part A*, 24, 303-312.

Friedlaender, Anne. 1990. "Discussion," In Alicia H. Munnell (ed.), *Is There A Shortfall in Public Capital Investment?*, Proceedings of Federal Reserve Bank of Boston conference.

Flores de Frutos, R. and Pereira, A. "Public Captial and Aggregate Growth in the United States: Is Public Capital Productive?" University of California, San Diego Discussion Paper, July 1993.

Garcia-Mila, Teresa, McGuire, Therese J. and Porter, Robert H. 1996. "The Effect of Public Capital in State-level Production Functions Reconsidered," *The Review of Economics and Statistics*, 78, 177-180.

Gillen, David W. 1996. "Transportation Infrastructure and Economic Development: A Review of Recent Literature," *Logistics and Transportation Review*, 32, 39-61.

Harmatuck, Donald J. 1996. "The Influence of Transportation Infrastructure on Economic Development," *Logistics and Transportation Review*, 32, 63-76.

Haughwout, Andrew F. 1998. "Aggregate Production Functions, Interregional Equilibrium, and the Measurement of Infrastructure Productivity," *Journal of Urban Economics*, 44, 216-227.

Hulten, Charles R. and Schwab, Robert M. 1991. "Is There Too Little Public Capital? Infrastructure and Economic Growth," *American Enterprise Institute Discussion Paper*, February 1991.

Holtz-Eakin, Douglas. 1994. "Public Sector Capital and the Productivity Puzzle," The Review of Economics and Statistics, 76, 12-21.

Holtz-Eakin, Douglas and Schwartz, Amy E. 1995. "Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways," *International Tax and Public Finance*, 2, 459-468.

Kelejian, Harry H. and Dennis P. Robinson. 1994. "Infrastructure Productivity: A Razor's Edge," Working Paper No. 94-3. College Park, MD: University of Maryland Department of Economics

Kelejian, Harry H. and Dennis P. Robinson 1997. "Infrastructure productivity estimation and its underlying econometric specifications: A sensitivity analysis," *Papers in Regional Science*, 76, 115-131.

Mikelbank, Brian A. and Jackson, Randall W. 2000. "The Role of Space in Public Capital Research," *International Regional Science Review*, 23, 235-258.

Moomaw, Ronald L., Mullen, John K., and Williams, Martin. 1995. "The interregional impact of infrastructure capital," *Southern Economic Journal*, 61, 830-845.

Morrison, Catherine J. and Schwartz, Amy E. 1996. "State Infrastructure and Productive Performance," *The American Economic Review*, 86, 1095-1111.

Munnell, Alicia. H. 1990. "How Does Infrastructure Affect Regional Economic Performance?" In Alicia H. Munnell (ed.), *Is There A Shortfall in Public Capital Investment?*, Proceedings of Federal Reserve Bank of Boston conference.

Munnell, Alicia H. 1992. "Policy Watch: Infrastructure Investment and Economic Growth" *Journal of Economic Perspectives*, 6, 189-98

Nadiri, M. Ishaq and Mamuneas, Theofanis P. 1994. "The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of U.S. Manufacturing Industries" *Review of Economics and Statistics*, 76, 22-37

Rephann, Terance and Isserman, Andrew. 1994. "New Highways as Economic Development Tools: An Evaluation Using Quasi-Experimental Matching Methods," *Regional Science and Urban Economics*, 24, 723-751.

Tatom, John A. 1993. "The Spurious Effect of Public Capital Formation on Private Sector Productivity," *Policy Studies Journal*, 21, 391-395.

Tatom, John A. 1991. "Public Capital and Private Sector Performance" *Federal Reserve Bank of St. Louis Review*, 73, 3-15.

Tatom, John A. "Paved with Good Intentions: The Mythical National Infrastructure Crisis" Policy Analysis, Cato Institute, Aug 12 1993.

Interjurisdictional Tax Competition Literature

Bucovetsky, S. 1991. "Asymmetric Tax Competition," *Journal of Urban Economics*, 30, 167-181.

Lee, Kangoh. 1997. "Tax Competition with Imperfectly Mobile Capital," *Journal of Urban Economics*, 42, 222-242.

Oates, William E. and Schwab, Robert M. 1988. "Economic Competition Among Jurisdictions: Efficiency Enhancing or Distortion Inducing?" *Journal of Public Economics*, 35, 333-354.

Wilson, John Douglas. 1986. "A Theory of Interregional Tax Competition," *Journal of Urban Economics*, 19, 296-315.

Wilson, John Douglas. 1991. "Tax Competition with Interregional Differences in Factor Endowments," *Regional Science and Urban Economics*, 21, 423-451.

Wilson, John Douglas. 1995. "Mobile Labor, Multiple Tax Instruments, and Tax Competition," *Journal of Urban Economics*, 38, 333-356.

Wildasin, David E. 1988. "Nash Equilibria in Models of Fiscal Competition," *Journal of Public Economics*, 35, 229-240.

Wheaton, William C. 1995. "Competition over Capital Taxation in a Two-region Economy," *MIT Center for Real Estate*, February 1995.

Zodrow, George R. and Peter Mieszkowski. 1986. "Pigou, Tiebout, Property Taxation, and the Underprovision of Local Public Goods," *Journal of Urban Economics*, 19, 356-370.

CHAPTER 2

Models of Highway Investment and Economic Spillovers

The argument for decentralizing highway finance is based on an idea that people who benefit from highways pay for them, and those who do not benefit from them should not have to do so (Boarnet, 1998). Since several researchers have found that highways exert a negative economic impact on areas that are distant from them (Rephann and Isserman, (1994); Kelejian and Robinson (1997); Boarnet, 1998; Chandra and Thompson, 2000), the current finance system in the US can cause a peculiar instance where people whose welfare is harmed by certain new highways may have to contribute to funding them through federal taxes. Hence, some researchers and practitioners have advocated a reform in highway finance, a new system where funds for building new highways come from jurisdictions along them (Boarnet and Haughwout, 2000). This has begun to be translated into public policies. For example, the Transportation Equity Act of the 21st Century (TEA-21) has explicit provisions that require states to pay into highway funds.

While the possibility of financial responsibility mismatch under the centralized system is a valid concern, it is not clear how a more decentralized system would influence highway investment decisions by responsible governments. The main reason for the centralized policy is that local and state governments might fail to internalize positive impacts of such investments on their neighbors, thereby under-investing in highways[1]. However, according to the recent literature, the current level of national highway stock in the US is substantial, and marginal highway investments no longer

[1] While this rationale might remain true in rural areas with under-developed highway network, its applicability to highly urbanized areas with extensive highway network is dubious. For example, evidence

produce far-reaching growth impacts as they used to (Fernald, 1999). A more important impact is the movement of business activities from other places to locations near highways – the major reason for the call for decentralizing highway finance (Boarnet and Haughwout, 2000). But, even without such relocations, Taylor (1992) argued that decentralized jurisdictions might have rent-seeking incentives to over-provide infrastructure to attract new[2] businesses. Therefore, negative spillovers in the form of factor migration, induced by new highways, provide all the more incentives for decentralized governments to compete in highway building in order to attract businesses and employment from their neighbors, thus over-investing in it. This is the central problem that I aim to shed light on in this chapter.

I employ economic modeling techniques that have been widely used in the inter-jurisdictional tax and infrastructure competition to explain possible outcomes of highway finance decentralization (Oates and Schwab, 1988; Bucovetsky, 1991; Wheaton, 1995). Like many researchers, I focus on a family of models that considers only the production sector and ignores households. This has two advantages: (1) the models are much more tractable with only the production sector, and (2) the issue at hand, spillovers in the form of employment migration, can be studied without confounding effects from households' decision making processes. As such, it is assumed that policymakers trade off between the productivity benefits of highway investment and the highway costs. Four models, from a basic single-region model to an asymmetric model, are presented in succession, followed by numerical simulations. Several conclusions about the impacts of the

often supports the view that recent transportation investments no longer have significant impact on land use or in shaping urban development (Giuliano, 1995).

[2] as opposed to existing businesses somewhere else.

decentralization on investment decision of governments are drawn based on assumptions about production technology and highway cost functions.

2.1 A Closed Economy

A metropolitan area with a closed economy, i.e fixed labor and land supply, has the following aggregate production function.

$$q = g(H_0)f(N, L), \tag{2.1}$$

where q = aggregate output, H_0 = existing highway stock, N = labor, L = land.

The production function, $f(\cdot)$, is homogenous of degree one in private factors, which include only labor and land. The marginal products of private factors are positive and decreasing. In addition, the shift function, $g(\cdot)$, which reflects the contribution of highway on production has similar properties; i.e., $g'(\cdot)$ is positive, and $g''(\cdot)$ is negative.

The government considers an incremental investment of amount h in highway. The cost function of highway is $C(h)$ where the marginal cost of highway $C'(h)$ is positive. Assumptions about the properties of the cost function are critical to the government's decision on highway investment. Small (1992) surveyed empirical studies on returns to scale of urban road construction. He concluded that, on average, mild scale economies are present in urban road construction. He noted also that as urban densities increase, land acquisition costs and other costs, such as those associated with intersections may rise substantially, leading to no economies or even diseconomies of scale. Since the focus of this study is on highly urbanized metro areas, it is reasonable to assume diseconomies in the cost function.

The government chooses the level of highway investment based on the net benefits of highways, that is the difference between benefits and costs. In this particular study, the measure of benefits of highways is the change in output. In the case of a closed region, this change results exclusively from increased productivity from highway stock.[3] Assuming that firms do not substitute the public factor for private inputs, the benefit of investing a small increment h in highway is:

$$B(h) = q_1 - q_0 = [g(H_0 + h) - g(H_0)]f(N,L),$$

where $B(h)$ is the benefits from investing an h increment of highway, and q_0 and q_1 are aggregate output before and after the investment, respectively. Since it is quite reasonable to assume diminishing returns to highway building ($g''(\cdot)$ is negative), the benefit function of highway is also positive and decreasing.

The government maximizes the net benefit of the investment.

$$\text{Max}_h \; NB(h) = B(h) - C(h)$$

$$\text{Max}_h \; NB(h) = [g(H_0 + h) - g(H_0)]f(N,L) - C(h) \tag{2.2}$$

The first order condition is

$$g'(H_0 + h)f(N,L) = C'(h) \tag{2.3}$$

If $g''(\cdot)$ is negative and $C''(\cdot)$ is positive, $NB''(h)$ is negative and the second order condition is met. The first order condition in equation (2.3) can be interpreted as the government's policy to expand highway stock until the marginal (production) benefits of highway equal marginal costs – the familiar criterion for cost-benefit analysis. Because there is no externality from highways in this model, the investment decision is efficient from the pareto viewpoint.

[3] However, if workers are freely mobile, such increased productivity may trigger a rise in employment, which further expands output.

2.2 A Closed Economy with Elastic Labor Supply

In this section, I relax the assumption that labor supply is fixed. Since an increase in highway stock will raise marginal products of factors, if labor supply is elastic, profit-maximizing firms will hire more workers until the marginal product of labor equals wage. Before the highway investment, the marginal product of labor is:

$$MP_L = g(H_0)\left.\frac{\partial f(n,L)}{\partial n}\right|_N = w_0 .$$

After the investment, this becomes:

$$MP_L = g(H_0 + h)\left.\frac{\partial f(n,L)}{\partial n}\right|_{N+\Delta n} = w_1 .$$

For a marginal increase in highway stock, the change in employment (Δn) due to wage increase is small. If I assume that wage elasticity of labor is a constant e, I can estimate the new wage by:

$$w_1 = g(H_0 + h)\left.\frac{\partial f(n,L)}{\partial n}\right|_N$$

The increase in labor supply is therefore:

$$\Delta n = e \cdot \left(\frac{w_1 - w_0}{w_0}\right) \cdot N$$

The government is faced with the same cost function as in the case of inelastic labor supply. On the benefit side, however, two factors contribute to output expansion, including productivity boosts from highways (same as in the previous model), and increased employment that is induced by the rise in wage. To maximize the net output expansion, the government takes the increase in employment into its investment considerations. While this investment decision is not social-welfare-maximizing in an economic sense, it is a plausible action by government officials because they often associate a great deal of prestige and perks with growth and development. The policymakers perceive job growth as benefits of highway although they are actually transfers between regions.In any case, the objective function (2.2) becomes:

$$\text{Max}_h \; NB(h) = [g(H_0 + h) f(N + \Delta n, L) - g(H_0) f(N, L)] - C(h) \quad (2.4)$$

The first order condition is:

$$g'(H_0 + h) f(N + \Delta n, L) + g(H_0 + h) \frac{\partial f(N + \Delta n, L)}{\partial h} = C'(h)$$

$$g'(H_0 + h) f(N + \Delta n, L) + g(H_0 + h) \frac{\partial f(N + \Delta n, L)}{\partial \Delta n} \frac{d\Delta n}{dh} = C'(h) \quad (2.5)$$

In this case, the interpretation of the first order condition changes slightly. Since the "perceived" benefits of highway investment come not only from the productivity effect of highway stock, but also from the increase in employment (Δn), the government will expand the highway stock until the marginal benefits from increases in both highway stock and employment equal the marginal costs. If I assume that Δn is small, compared to N, then the second term on the left-hand side of equation (2.5) may be dropped. Because $g'(\cdot)$ is increasing and $C'(\cdot)$ is declining with h, the increase in $f(\cdot)$ due to Δn implies that the optimal investment h^* that satisfies equation (2.5) will be larger than that in the case of fixed labor supply (equation (2.3)).

2.3 Two Identical Regions, Mobile Labor, Unilateral Investment

In this section, I use a two-region model to examine economic spillovers of highway investment in one region (unilateral investment). Assume that the two regions have identical production functions with the same properties as those of the above models. Also, aggregate labor supply, i.e., the sum of labor in the two regions, is fixed.

Workers, however, are freely mobile between regions. Due to symmetry, the pre-investment conditions of wage and land rent are identical and equal to marginal products of labor and land, respectively. With equal wage, workers are indifferent between regions. If one region (region 1) decides to invest more in highway, it will raise the marginal product of labor in that region, and the wage thereof. Because of wage disparity, workers in the other region (region 2) will move to region 1. As a result, the marginal product (and wage) in region 2 will increase gradually, and at the same time marginal product of labor in region 1 will decline. The adjustment continues until the wage equality condition is restored. The adjustment of the wage equality condition can be written as follows:

$$w_1 = g(H_0 + h)\frac{\partial f(n_1 + \Delta n, L)}{\partial n} = w_2 = g(H_0)\frac{\partial f(n_2 - \Delta n, L)}{\partial n} \qquad (2.6)$$

where Δn is the net migration (change in employment) that satisfies equation (2.6).

The changes in regional outputs are given by:

$$\Delta q_1 = g(H_0 + h)f(n_1 + \Delta n, L) - g(H_0)f(n_1, L) \qquad (2.7)$$

$$\Delta q_2 = g(H_0)[f(n_2 - \Delta n, L) - f(n_2, L)] \qquad (2.8)$$

As discussed earlier, the increase in output in region 1 is perceived by policymakers of that region as benefits while the loss in region 2 is not considered. Region 1 is also faced with the same cost function as in the previous models, and from its point of view, this is the only cost of highway investment. Hence, under the decentralized scheme of highway finance, the local government, expecting employment gain from in-migration and disregarding output losses of the other region, maximizes local net benefit (*LNB*), i.e.,

$$\text{Max}_h \; LNB(h) = \Delta q_1(h) - C(h)$$

$$\text{Max}_h\ g(H_0 + h)f(n_1 + \Delta n, L) - g(H_0)f(n_1, L) - C(h)$$

However, under the centralized scheme of highway finance, the central government must internalize the output loss in region 2. Its objective function is to maximize aggregate net benefits (*ANB*):

$$\text{Max}_h\ ANB(h) = \Delta q_1(h) + \Delta q_2(h) - C(h)$$

$$\text{Max}_h\ g(H_0 + h)f(n_1 + \Delta n, L) - g(H_0)f(n_1, L)$$

$$+ g(H_0)f(n_2 - \Delta n, L) - g(H_0)f(n_2, L) - C(h) \tag{2.9}$$

Using the same rationale as in the previous section, I can deduce that the optimal investment, h^*, in the case of decentralized finance is higher than in the case of centralized finance. Simulation results will confirm this and will also show that the aggregate net benefits of the decentralized investments are sub-optimal. See section 2.1.5 for model simulations.

2.4 Two Identical Regions, Mobile Labor, Bilateral Investments

The previous section deals with the case of unilateral investment only. Bilateral investments are considered in this section. When the highway finance decision is decentralized within the metro area, an individual government will not take the output loss of the other jurisdiction, due to employment relocation, into its investment decision. It will, therefore, over-invest in highways. The government of the neighboring region, which stands to lose, will be forced to take action, in order to keep employment from relocating. Its action, whether to invest more in highway and by how much, depends on what the other has done. Hence, the outcome of this problem can be analyzed by the game-theoretic framework.

Suppose that region 1 invests a small amount h in highways. Region 2 has three available strategies: (1) it can match the investment, h, (2) it can invest more than h, or (3) it can invest a smaller amount than h (including zero). The pay-off of each strategy depends on the level of h. At small h, region 2 can invest more than h, without incurring high costs. If region 1 does not change its highway stock, region 2 will be able to attract labor from region 1. In this way, the pay-off of this strategy will be higher than the other two. However, with the threat of out-migration, region 1 will likely counter by matching region 2 investment, and may also increase its highway stock beyond that level, given that the benefits from highway productivity and labor migration are greater than the costs. But as each region moves and counters, it will become increasingly expensive to build more highways. Nonetheless, the possibility of lagging behind and the threat of labor out-migration will keep them from stopping. Up to a certain point, however, building more highways will become so expensive that even the benefit from drawing labor from the other region is not enough to sustain the costs. At this point, both regions will stop investing. This is the Nash equilibrium, and under the symmetric assumption, both governments will equally over-invest in highways, but will have no effect on labor allocation between regions.

2.5 Asymmetric Model

In this section, I relax the assumption of identical regions. I focus on the disparity of initial highway endowment in each region, and how that, as well as new highway investments, affect employment allocation. An important consequence that must be considered is how this might change the benefit and cost functions of each region from the symmetric case. Different levels of highway stock, for example, implies that the region with more highways – I will call this region 1, is more productive than the other (region 2), and under labor mobility assumption, region 1 will be larger, in terms of employment. Further, because region 1 has more employment, marginal investment in the same amount of highway in region 1 will increase output more than in region 2. Thus, in the central government point of view, investing in region 1 seems to make more sense because of its higher rate of returns.

However, the region with a lot of highways is likely more urbanized and denser than is the region with relatively little highway capacity. Since the two regions have different degrees of urbanization and residential densities, they will be faced with different cost functions of highway building (Small, 1992). For example, the costs of building highways in a central city are likely much higher than they are in suburbs because they involve acquisition of more expensive land for right of way, relocation of many residents, costs of clearing and demolition of existing buildings, etc. While it is still reasonable to assume diseconomies of scale in the central city, in the suburb where there is more open space, highway construction may exhibit less severe diseconomies or even mild economies of sale. In this case, even though benefits from highways in the central city are high, they may be offset by high costs. In contrast, because building more highways in the suburbs is less costly, it may be more beneficial to expand highway stock there, despite the low productivity benefits.

To examine the trade-off between productivity benefits and costs of highways, I will use highway investment cost functions with different characteristics for each region in the numerical simulations. Note that with increasing returns, it is possible that marginal benefits and marginal costs do not intercept. This can happen if marginal benefits decrease more slowly than do marginal costs. In this case, output can be expanded as long as the government keeps building highways, an unlikely outcome. In numerical simulations, therefore, the cost functions are chosen to prevent this problem from occurring.

2.6 Model Simulations

A closed economy

Assume that the closed region in section 2.1.1 has the Cobb-Douglas aggregate production function $q = H_0^c N^a L^{1-a}$ with the parameters $c = 0.1$ and $a = 0.8$, and that the existing highway stock $H_0 = 1$, employment $N = 100$, and land $L = 100$. Assume also that the cost function of highway is given by $C(h) = k \cdot h^s$, where h is the amount of highway investment and $1/s$ is the degree of economies of scale. As discussed earlier, I assume that highway expansion in this region exhibits diseconomies of scale, and the values of k and s are 1000 and 2, respectively. Table 2.1 shows the results for various values of h, and the corresponding net benefit.

Table 2.1 Simulation Results for a Closed Region

H	*Q*	*TB*	*TC*	*NB*
1.000	100			
1.001	100.01000	0.01000	0.001	0.00900
1.002	100.01998	0.01998	0.004	0.01598
1.003	100.02996	0.02996	0.009	0.02096
1.004	100.03993	0.03993	0.016	0.02393
1.005	**100.04989**	**0.04989**	**0.025**	**0.02489**
1.006	100.05984	0.05984	0.036	0.02384
1.007	100.06978	0.06978	0.049	0.02078
1.008	100.07971	0.07971	0.064	0.01571
1.009	100.08964	0.08964	0.081	0.00864
1.010	100.09955	0.09955	0.100	-0.00045

Total Benefits (*TB*) is the difference between output before and after the investment is made, Total Costs (*TC*) is computed from the cost function, and Net Benefits (*NB*) is the difference between *TB* and *TC*. The results show that the optimal level of investment is 0.5% of the original highway stock, at which point *NB* is maximized at 0.025. Beyond this point, the net benefits decline because the cost of highway expansion becomes prohibitively expensive. The net benefits become negative when the investment exceeds 1% of the original highway stock.

A closed economy with elastic labor supply

The same set of assumptions about aggregate production function as used in the case of closed economy is applied for this simulation. In addition, I assume that the wage elasticity of labor supply is 0.2. The results in Table 2.2 show that the total benefits increase at each level of investment thanks to employment-induced output expansion. The optimal level of investment increases to 0.6% of the original highway stock. The Net Benefits increase from 0.025% to 0.033% of the initial output.

Table 2.2 Simulation Results for a Closed Region with Elastic Labor Supply

H	*Q*	*TB*	*TC*	*NB*
1.000	100			
1.001	100.01159	0.01159	0.001	0.01059
1.002	100.02318	0.02318	0.004	0.01918
1.003	100.03475	0.03475	0.009	0.02575
1.004	100.04632	0.04632	0.016	0.03032
1.005	100.05787	0.05787	0.025	0.03287
1.006	**100.06942**	**0.06942**	**0.036**	**0.03342**
1.007	100.08095	0.08095	0.049	0.03195
1.008	100.09248	0.09248	0.064	0.02848
1.009	100.10399	0.10399	0.081	0.02299
1.010	100.11550	0.11550	0.100	0.01550

Two-region, mobile labor, unilateral investment

In this section, I simulate a unilateral highway investment decision of a decentralized metro area with two identical regions. The same set of assumptions about aggregate production function and highway costs as in the case of single region are used, and all parameters remain unchanged. For each level of highway investment in one region, I will call this region 1, I can compute the net migration (Δn) that satisfies that wage equality condition below.

$$w_1 = (1+h)^{0.1} \cdot 0.8 \cdot (100+\Delta n)^{-0.2} (100)^2 = w_2 = 1^{0.1} \cdot 0.8 \cdot (100-\Delta n)^{-0.2} (100)^2$$

$$(1+h)^{0.1} = \left(\frac{100+\Delta n}{100-\Delta n}\right)^{0.2}$$

$$1+h = \left(\frac{100+\Delta n}{100-\Delta n}\right)^{2}$$

The changes in outputs in both regions can be computed from the net migration. The local net benefits (*LNB*) and aggregate net benefits (*ANB*) from unilateral investment are then calculated and the results are shown in Table 2.3.

Table 2.3 Simulation Results for a Unilateral Highway Investment with Labor Migration in a Two-Region Model

H	Δn	*W*	Δq_1	Δq_2	*C*(*h*)	$LNB = \Delta q_1 - C(h)$	$ANB = \Delta q_1 + \Delta q_2 - C(h)$
1.001	0.025	0.8000	0.0300	-0.0200	0.001	0.0290	0.0090
1.002	0.050	0.8001	0.0600	-0.0400	0.004	0.0560	0.0160
1.003	0.075	0.8001	0.0900	-0.0600	0.009	0.0810	0.0210
1.004	0.100	0.8002	0.1200	-0.0800	0.016	0.1040	0.0239
1.005	**0.125**	**0.8002**	**0.1499**	**-0.1000**	**0.025**	**0.1249**	**0.0249**
1.006	0.150	0.8002	0.1799	-0.1200	0.036	0.1439	0.0239
1.007	0.175	0.8003	0.2099	-0.1400	0.049	0.1609	0.0208
1.008	0.200	0.8003	0.2398	-0.1600	0.064	0.1758	0.0158
1.009	0.225	0.8004	0.2698	-0.1800	0.081	0.1888	0.0087
1.010	0.250	0.8004	0.2997	-0.2001	0.100	0.1997	-0.0003
1.011	0.275	0.8004	0.3296	-0.2201	0.121	0.2086	-0.0114
1.012	0.300	0.8005	0.3596	-0.2401	0.144	0.2156	-0.0245
1.013	0.325	0.8005	0.3895	-0.2601	0.169	0.2205	-0.0396
1.014	0.350	0.8006	0.4194	-0.2801	0.196	0.2234	-0.0567
1.015	***0.375***	***0.8006***	***0.4493***	***-0.3001***	***0.225***	***0.2243***	***-0.0758***
1.016	0.400	0.8006	0.4792	-0.3201	0.256	0.2232	-0.0969
1.017	0.425	0.8007	0.5091	-0.3401	0.289	0.2201	-0.1200

If the region internalizes the output loss experienced by the non-investing region, or region 2, the optimal investment is 0.5% of the original highway stock. At this level, *ANB* is maximized at 0.013% of the aggregate output. However, as can be seen in Table 2.3, *LNB* is maximized when the investing region increases highway stock by 1.5%. The region benefits from in-migration and its output grows by 0.22%, but this level of investment actually reduces the aggregate output by 0.038%. The simulation shows that under the decentralized highway finance decision, there can be an over-investment in highway.

Two-region, mobile labor, bilateral investments

Table 2.4 shows simulation results for the actions of region 2 after the investment by region 1. If region 2 does not counter by investing more in highway, it will lose 0.375% of its employment and 0.3% of its output. If, on the other hand, region 2 invests more, its employment loss will decline, and so will its output loss, up to the point where its investment level equals that of region 1. Beyond this point, the costs of highway investment overwhelm labor migration benefits.

Under the game-theory framework, each level of highway investment, in the second column of Table 2.4, can be thought of as region 2's set of strategies, and the final column, LNB_2 as its pay-off schedule. At the beginning, region 2 becomes better off by investing more and more in highway, until it matches the level invested by region 1. At this point, both regions have no incentive to increase or reduce their level of highway investments because that would only make them worse off. Each region investing at 1.5% of their original highway stock and suffering 0.08% net loss is therefore the Nash equilibrium.

The highway investment under Nash equilibrium has no impact on allocation of labor between the two regions. This allocation outcome is similar to the case of immobile labor in section 2.1.1. In that case, the optimal level of investment is 0.5%, and the *LNB* is 0.025%. This means that if both regions invest at this level, they will enjoy positive net benefits, and the aggregate net benefits will be maximized at 0.05%. Such cooperative investment, however, is not enforceable because each region will have incentives to defect by investing more in order to attract employment from the other region. As a result, this simulation shows that the race-to-the-bottom problem is possible under the decentralized scheme of highway finance.

Table 2.4 Simulation Results for Bilateral Highway Investments in a Two-Region Model

H_1	H_2	W	Δn	Δq_1	Δq_2	$C(h_1)$	$C(h_2)$	LNB_1	LNB_2
1.015	1.000	0.8006	0.375	0.4493	-0.3001	0.225	0.000	0.2201	-0.3011
1.015	1.001	0.8006	0.350	0.4293	-0.2701	0.225	0.001	0.2043	-0.2711
1.015	1.002	0.8007	0.325	0.4093	-0.2402	0.225	0.004	0.1843	-0.2442
1.015	1.003	0.8007	0.300	0.3893	-0.2102	0.225	0.009	0.1643	-0.2192
1.015	1.004	0.8008	0.275	0.3693	-0.1802	0.225	0.016	0.1443	-0.1962
1.015	1.005	0.8008	0.250	0.3492	-0.1503	0.225	0.025	0.1242	-0.1753
1.015	1.006	0.8008	0.225	0.3292	-0.1203	0.225	0.036	0.1042	-0.1563
1.015	1.007	0.8009	0.200	0.3092	-0.0904	0.225	0.049	0.0842	-0.1394
1.015	1.008	0.8009	0.175	0.2892	-0.0604	0.225	0.064	0.0642	-0.1244
1.015	1.009	0.8010	0.150	0.2692	-0.0305	0.225	0.081	0.0442	-0.1115
1.015	1.010	0.8010	0.125	0.2491	-0.0006	0.225	0.100	0.0241	-0.1006
1.015	1.011	0.8010	0.100	0.2291	0.0294	0.225	0.121	0.0041	-0.0916
1.015	1.012	0.8011	0.075	0.2091	0.0593	0.225	0.144	-0.0159	-0.0847
1.015	1.013	0.8011	0.050	0.1891	0.0892	0.225	0.169	-0.0359	-0.0798
1.015	1.014	0.8012	0.025	0.1690	0.1191	0.225	0.196	-0.0560	-0.0769
1.015	**1.015**	0.8012	0.000	0.1490	0.1490	0.225	0.225	**-0.0760**	**-0.0760**
1.015	1.016	0.8012	-0.025	0.1290	0.1789	0.225	0.256	-0.0960	-0.0771
1.015	1.017	0.8013	-0.050	0.1089	0.2088	0.225	0.289	-0.1161	-0.0802
1.015	1.018	0.8013	-0.075	0.0889	0.2387	0.225	0.324	-0.1361	-0.0853
1.015	1.019	0.8014	-0.100	0.0689	0.2685	0.225	0.361	-0.1561	-0.0925
1.015	1.020	0.8014	-0.125	0.0488	0.2984	0.225	0.400	-0.1762	-0.1016
1.015	1.021	0.8014	-0.150	0.0288	0.3283	0.225	0.441	-0.1962	-0.1127

Simulations of the asymmetric model

Although all assumptions about production functions and highway costs are unchanged, I use different sets of parameters to reflect the asymmetry of the two-region metro area. Table 2.5 summarizes parameters for the two regions.

Table 2.5 Summary of Parameters for Asymmetric Model Simulations

	Region 1	Region2
Production function		
$q = H^c N^a L^{1-a}$		
H	1	0.25
N	100	20
L	100	40
A	0.8	0.8
C	0.1	0.1
Highway cost function		
$C(h) = k \cdot h^s$		
K	1000	100
S	2	1.5

Table 2.6 and 2.7 show simulation results of unilateral investment in region 1 and 2, respectively. As can be seen, both regions will over-invest if they act independently. Region 1 will over-invest by 60%, judging by the optimal aggregate net benefit criterion. This is very little compared to region 2, where the decentralized government will invest 13 times as much as the centralized one would in order to lure employment from region 1. This is so because highway costs are less expensive and will be offset by the benefits of increased employment. As a result, despite the local net benefit of 2.6% of output in region 2, aggregate net benefit is negative, with output shrinkage region 1 offsetting the *LNB* of region 2.

Table 2.6 Simulation Results for a Unilateral Highway Investment in Region 1 in an Asymmetric Model

H_1	Δn	N_1	N_2	W	Δq_1	Δq_2	$C(h)$	LNB	ANB
1.001	0.0084	100.0084	19.9916	0.8001	0.0167	-0.0067	0.001	0.0157	0.0090
1.002	0.0166	100.0166	19.9834	0.8001	0.0333	-0.0133	0.004	0.0293	0.0160
1.003	0.0250	100.0250	19.9750	0.8002	0.0500	-0.0200	0.009	0.0410	0.0210
1.004	0.0333	100.0333	19.9667	0.8003	0.0666	-0.0266	0.016	0.0506	0.0239
1.005	**0.0414**	**100.0414**	**19.9586**	**0.8003**	**0.0830**	**-0.0331**	**0.025**	**0.0580**	**0.0249**
1.006	0.0500	100.0500	19.9500	0.8004	0.0999	-0.0400	0.036	0.0639	0.0239
1.007	0.0580	100.0580	19.9420	0.8005	0.1162	-0.0464	0.049	0.0672	0.0208
1.008	***0.0665***	***100.0665***	***19.9335***	***0.8005***	***0.1330***	***-0.0532***	***0.064***	***0.0690***	***0.0157***
1.009	0.0746	100.0746	19.9254	0.8006	0.1494	-0.0597	0.081	0.0684	0.0087
1.010	0.0828	100.0828	19.9172	0.8007	0.1659	-0.0663	0.100	0.0659	-0.0004
1.011	0.0909	100.0909	19.9091	0.8007	0.1823	-0.0728	0.121	0.0613	-0.0115
1.012	0.0992	100.0992	19.9008	0.8008	0.1988	-0.0794	0.144	0.0548	-0.0246
1.013	0.1075	100.1075	19.8925	0.8009	0.2153	-0.0860	0.169	0.0463	-0.0397
1.014	0.1156	100.1156	19.8844	0.8009	0.2317	-0.0925	0.196	0.0357	-0.0568
1.015	0.1237	100.1237	19.8763	0.8010	0.2481	-0.0990	0.225	0.0231	-0.0759

Table 2.7 Simulation Results for a Unilateral Highway Investment in Region 2 in an Asymmetric Model

H_2	Δn	N_1	N_2	W	Δq_1	Δq_2	$C(h)$	LNB	ANB
1.001	0.0333	99.9667	20.0333	0.8001	-0.0266	0.0346	0.003	0.0315	0.0048
1.002	0.0665	99.9335	20.0665	0.8001	-0.0532	0.0692	0.009	0.0602	0.0070
1.003	0.0996	99.9004	20.0996	0.8002	-0.0797	0.1036	0.016	0.0872	0.0075
1.004	0.1327	99.8673	20.1327	0.8002	-0.1062	0.1380	0.025	0.1127	0.0066
1.005	**0.1656**	**99.8344**	**20.1656**	**0.8003**	**-0.1325**	**0.1723**	**0.035**	**0.1369**	**0.0044**
1.006	0.1985	99.8015	20.1985	0.8003	-0.1588	0.2065	0.046	0.1600	0.0012
1.007	0.2312	99.7688	20.2312	0.8004	-0.1850	0.2406	0.059	0.1820	-0.0030
1.008	0.2638	99.7362	20.2638	0.8004	-0.2111	0.2745	0.072	0.2030	-0.0081
1.009	0.2965	99.7035	20.2965	0.8005	-0.2373	0.3085	0.085	0.2232	-0.0141
1.010	0.3290	99.6710	20.3290	0.8005	-0.2633	0.3424	0.100	0.2424	-0.0209
1.011	0.3615	99.6385	20.3615	0.8006	-0.2893	0.3762	0.115	0.2609	-0.0284
1.012	0.3937	99.6063	20.3937	0.8006	-0.3151	0.4098	0.131	0.2784	-0.0367
1.013	0.4261	99.5739	20.4261	0.8007	-0.3410	0.4435	0.148	0.2953	-0.0457
1.014	0.4582	99.5418	20.4582	0.8007	-0.3667	0.4770	0.166	0.3113	-0.0554
1.015	0.4903	99.5097	20.4903	0.8008	-0.3924	0.5105	0.184	0.3267	-0.0657
1.030	0.9640	99.0360	20.9640	0.8015	-0.7719	1.0042	0.520	0.4846	-0.2873
1.035	1.1170	98.8830	21.1170	0.8018	-0.8946	1.1642	0.655	0.5094	-0.3852
1.036	1.1450	98.8550	21.1450	0.8019	-0.9171	1.1941	0.683	0.5110	-0.4060
1.037	1.1800	98.8200	21.1800	0.8019	-0.9451	1.2296	0.712	0.5178	-0.4273
1.038	1.2100	98.7900	21.2100	0.8019	-0.9692	1.2610	0.741	0.5202	-0.4489
1.039	***1.2390***	***98.7610***	***21.2390***	***0.8020***	***-0.9924***	***1.2916***	***0.770***	***0.5214***	***-0.4710***
1.040	1.2600	98.7400	21.2600	0.8021	-1.0093	1.3158	0.800	0.5158	-0.4934
1.050	1.5650	98.4350	21.5650	0.8025	-1.2540	1.6333	1.118	0.5153	-0.7387
1.060	1.8580	98.1420	21.8580	0.8030	-1.4892	1.9400	1.470	0.4703	-1.0189
1.070	2.1400	97.8600	22.1400	0.8035	-1.7157	2.2366	1.852	0.3846	-1.3311
1.080	2.4200	97.5800	22.4200	0.8039	-1.9407	2.5306	2.263	0.2678	-1.6729

Table 2.8 shows simulation results of locally optimal investments[4] under centralized investment decision. The optimal investment is determined by the following procedure. First, a local optimum can be found by fixing the level of investment in region 1 and varying the level in region 2 until aggregate net benefit is maximized. In Table 2.9, for example, the level of investment in region 1 is fixed at 0.005, the locally optimal investment in region 2 is 0.003. Then, by varying the level of investment in region 1, other locally optimal investments in region 2 can be computed in the same fashion. The

[4] This is defined by the optimal (*ANB* maximizing) investment in one region, given an investment in the other.

procedure is repeated until the global optimum is found. This is the locally optimal investment, which maximizes the *ANB*, among all other local optimums. The optimal investments in region 1 and 2 are 0.005 and 0.003, respectively. At this point, the aggregate net benefit is maximized at 0.0323, and the allocation of employments between the two regions changes relatively little, compared to other cases. The results show the ability of the centralized government to exploit the high rate of returns in both regions, due to productivity benefits in region 1 and low costs of highway in region 2, without causing significant relocation of employment.

Table 2.8 Locally Optimal Investments under Centralized Investment Decision

H_1	H_2	Δn	N_1	N_2	W	Δq_1	Δq_2	$C(h_1)$	$C(h_2)$	***ANB***
1.001	0.253	-0.0911	99.9089	20.0911	0.8002	-0.0629	0.0968	0.0010	0.0164	0.0165
1.002	0.253	-0.0830	99.9170	20.0830	0.8003	-0.0464	0.0903	0.0040	0.0164	0.0235
1.003	0.253	-0.0745	99.9255	20.0745	0.8004	-0.0297	0.0835	0.0090	0.0164	0.0284
1.004	0.253	-0.0661	99.9339	20.0661	0.8004	-0.0130	0.0768	0.0160	0.0164	0.0314
1.005	**0.253**	**-0.0570**	**99.9430**	**20.0570**	**0.8005**	**0.0043**	**0.0695**	**0.0250**	**0.0164**	**0.0323**
1.006	0.253	-0.0497	99.9503	20.0497	0.8006	0.0201	0.0637	0.0360	0.0164	0.0313
1.007	0.253	-0.0413	99.9587	20.0413	0.8006	0.0367	0.0569	0.0490	0.0164	0.0282
1.008	0.253	-0.0332	99.9668	20.0332	0.8007	0.0531	0.0505	0.0640	0.0164	0.0232
1.009	0.253	-0.0249	99.9751	20.0249	0.8008	0.0697	0.0438	0.0810	0.0164	0.0161

Table 2.9 Locally Optimal Investments under Centralized Investment Decision when H_1 Fixed at 1.005

H_1	H_2	Δn	N_1	N_2	W	Δq_1	Δq_2	$C(h_1)$	$C(h_2)$	***ANB***
1.005	0.250	0.0414	100.0414	19.9586	0.8003	0.0830	-0.0331	0.0250	0.0000	0.0249
1.005	0.251	0.0082	100.0082	19.9918	0.8004	0.0565	0.0014	0.0250	0.0032	0.0297
1.005	0.252	-0.0250	99.9750	20.0250	0.8004	0.0299	0.0360	0.0250	0.0089	0.0319
1.005	**0.253**	**-0.0570**	**99.9430**	**20.0570**	**0.8005**	**0.0043**	**0.0695**	**0.0250**	**0.0164**	**0.0323**
1.005	0.254	-0.0910	99.9090	20.0910	0.8005	-0.0230	0.1047	0.0250	0.0253	0.0314
1.005	0.255	-0.1239	99.8761	20.1239	0.8006	-0.0493	0.1389	0.0250	0.0354	0.0293
1.005	0.256	-0.1566	99.8434	20.1566	0.8006	-0.0755	0.1730	0.0250	0.0465	0.0260

Table 2.10 and 2.11 show the simulation results for bilateral investment decisions under the decentralized investment decision. Table 2.10 shows benefits, costs, and employment allocation of moves and counter-moves of the two regions when region 1

moves first, and Table 2.11 when region 2 moves first. Like in the symmetric case, strategic behaviors of the two governments would lead to inefficient investments in both regions in the equilibrium – 0.008 and 0.043 in region 1 and 2, respectively. Consequently, the aggregate net benefit when decentralized governments behave strategically is –0.5482, compared to 0.0323, under the centralized investment decision.

Table 2.10 Simulation Results of Bilateral Investments: Region 1 Moves First

Second round: Investment in region 2 given the investment of 0.008 in region 1 in the first round

H_2	Δn	N_1	N_2	W	Δq_1	Δq_2	$C_1(h)$	$C_2(h)$	LNB_2	ANB
0.039	-1.1680	98.8320	21.1680	0.8025	-0.8565	1.2347	0.0640	0.7702	0.4645	-0.4560
0.040	-1.1980	98.8020	21.1980	0.8026	-0.8806	1.2661	0.0640	0.8000	0.4661	-0.4785
0.041	-1.2280	98.7720	21.2280	0.8026	-0.9047	1.2975	0.0640	0.8302	0.4673	-0.5014
0.042	-1.2580	98.7420	21.2580	0.8027	-0.9288	1.3289	0.0640	0.8607	0.4682	-0.5246
0.043	***-1.2879***	***98.7121***	***21.2879***	***0.8027***	***-0.9528***	***1.3602***	***0.0640***	***0.8917***	***0.4685***	***-0.5482***
0.044	-1.3178	98.6822	21.3178	0.8028	-0.9767	1.3915	0.0640	0.9230	0.4685	-0.5722
0.045	-1.3475	98.6525	21.3475	0.8028	-1.0006	1.4226	0.0640	0.9546	0.4680	-0.5966
0.046	-1.3772	98.6228	21.3772	0.8029	-1.0245	1.4537	0.0640	0.9866	0.4671	-0.6214
0.047	-1.4070	98.5930	21.4070	0.8029	-1.0484	1.4848	0.0640	1.0189	0.4659	-0.6465

Third round: Investment in region 1 given the investment of 0.043 in region 2 in the second round

H_1	Δn	N_1	N_2	W	Δq_1	Δq_2	$C_1(h)$	$C_2(h)$	LNB_1	ANB
0.008	***-1.2880***	***98.7121***	***21.2880***	***0.8027***	***-0.9528***	***1.3602***	***0.0640***	***0.8917***	***-1.0168***	***-0.5482***
0.009	-1.2793	98.7207	21.2793	0.8028	-0.9360	1.3532	0.0810	0.8917	-1.0170	-0.5554
0.010	-1.2706	98.7294	21.2706	0.8028	-0.9193	1.3463	0.1000	0.8917	-1.0193	-0.5646
0.011	-1.2620	98.7381	21.2620	0.8029	-0.9025	1.3394	0.1210	0.8917	-1.0235	-0.5758
0.012	-1.2533	98.7467	21.2533	0.8030	-0.8857	1.3324	0.1440	0.8917	-1.0297	-0.5890

Table 2.11 Simulation Results of Bilateral Investment: Region 2 Moves First

Second round: Investment in region 1 given the investment of 0.039 in region 2 in the first round

H_1	Δn	N_1	N_2	W	Δq_1	Δq_2	$C_1(h)$	$C_2(h)$	LNB_1	ANB
0.000	-1.2380	98.7620	21.2380	0.8020	-0.9916	1.2908	0.0000	0.7702	-0.9916	-0.4710
0.001	-1.2280	98.7720	21.2280	0.8021	-0.9737	1.2828	0.0010	0.7702	-0.9747	-0.4621
0.005	-1.1930	98.8070	21.1930	0.8023	-0.9061	1.2547	0.0250	0.7702	-0.9311	-0.4466
0.006	-1.1850	98.8150	21.1850	0.8024	-0.8899	1.2483	0.0360	0.7702	-0.9259	-0.4477
0.007	-1.1765	98.8235	21.1765	0.8025	-0.8732	1.2415	0.0490	0.7702	-0.9222	-0.4509
0.008	***-1.1679***	***98.8322***	***21.1679***	***0.8025***	***-0.8564***	***1.2346***	***0.0640***	***0.7702***	***-0.9204***	***-0.4560***
0.009	-1.1592	98.8408	21.1592	0.8026	-0.8396	1.2276	0.0810	0.7702	-0.9206	-0.4632
0.010	-1.1505	98.8495	21.1505	0.8027	-0.8228	1.2206	0.1000	0.7702	-0.9228	-0.4724
0.015	-1.1080	98.8920	21.1080	0.8030	-0.7397	1.1865	0.2250	0.7702	-0.9647	-0.5484
Third round: Investment in region 2 given the investment of 0.008 in region 2 in the second round										
H_2	Δn	N_1	N_2	W	Δq_1	Δq_2	$C_1(h)$	$C_2(h)$	LNB_2	ANB
0.039	-1.1679	98.8322	21.1679	0.8025	-0.8564	1.2346	0.0640	0.7702	0.4644	-0.4560
0.040	-1.1980	98.8020	21.1980	0.8026	-0.8806	1.2661	0.0640	0.8000	0.4661	-0.4785
0.041	-1.2281	98.7720	21.2281	0.8026	-0.9047	1.2975	0.0640	0.8302	0.4674	-0.5014
0.042	-1.2580	98.7420	21.2580	0.8027	-0.9288	1.3289	0.0640	0.8607	0.4681	-0.5246
0.043	***-1.2880***	***98.7121***	***21.2880***	***0.8027***	***-0.9528***	***1.3602***	***0.0640***	***0.8917***	***0.4686***	***-0.5482***
0.044	-1.3178	98.6822	21.3178	0.8028	-0.9768	1.3915	0.0640	0.9230	0.4685	-0.5722
0.045	-1.3476	98.6524	21.3476	0.8028	-1.0007	1.4227	0.0640	0.9546	0.4681	-0.5966
0.046	-1.3773	98.6227	21.3773	0.8029	-1.0245	1.4538	0.0640	0.9866	0.4672	-0.6214

2.7 Conclusion

The economic models in this section illustrate that despite negative spillovers of highway investment, the calls for decentralization of highway finance, intended to correct the problem of funding responsibility mismatch, might lead to yet another problem, over-investment in highways. The problem arises from strategic behaviors of decentralized governments, which aim to attract employment from their neighbors by providing more highways. Since these governments will: (1) fail to internalize the loss of economic activities in other jurisdictions and (2) need to invest enough to prevent the flight of their own employment base elsewhere, their investment decisions will lead to over-provisions of highways. The numerical simulations of the models confirm the race-to-the-bottom hypothesis. When local governments are allowed to decide on highway investment independently, they invariably choose the level of investment that far exceeds the optimal level that can be achieved by a centralized decision. These results also hold, regardless of the relative sizes of the regions.

The policy relevance of these results hinges critically on the geographic extent of negative spillovers. Researchers often found conflicting evidence of economic spillovers of highways at different geographic levels, but recent evidence suggests that negative spillovers are not significant in larger geographic area, such as states[5] (Holtz-Eakin and Schwartz, 1990; Kelejian and Robinson, 1997). Therefore, decentralization of highway finance at that level of governments may not trigger the race-to-the-bottom problem, as described in this chapter. On the other hand, there is quite a consensus in studies of smaller geographic areas, such as counties, that negative spillovers are real and significant (Rephann and Isserman, 1994; Boarnet, 1998; Chandra and Thompson, 2000). Unfortunately, these studies often utilized data from rural counties and none from lower geographic level, such as cities or towns. More studies are needed in order to help inform policy prescriptions for highway finance at the metropolitan level. If, for example, there is no evidence of spillovers, negative or otherwise, within metro areas, there may be no harm in decentralizing highway finance decision in order to deal with the problem of funding responsibility mismatch. To shed more light on this issue, economic spillovers of new highways at the metropolitan level is examined the next chapter.

References

Bucovetsky, S. 1991. "Asymmetric Tax Competition," *Journal of Urban Economics*, 30, 167-181.

[5] This is probably due to the relative difficulties of factor mobility among states, as opposed to among smaller geographic areas.

Oates, William E. and Schwab, Robert M. 1988. "Economic Competition Among Jurisdictions: Efficiency Enhancing or Distortion Inducing?" *Journal of Public Economics*, 35, 333-354.

Boarnet, Marlon G. 1998. "Spillovers and the Locational Effects of Public Infrastructure," *Journal of Regional Science*, 38, 381-400.

Boarnet, Marlon G. and Haughwout, Andrew F. 2000. "Do Highways Matter? Evidence and Policy Implications of Highways' Influence Metropolitan Development" A Discussion Paper Prepared for the Brooking Institution's Center on Urban and Metropolitan Policy, Washington, D.C.

Chandra, Amitabh and Thompson, Eric. 2000. "Does Public Infrastructure Affect Economic Activity? Evidence from the Rural Interstate Highway System," *Regional Science and Urban Economics*, 30, 457-490.

Fernald, John G. 1999. "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity," *American Economic Review*, 89, 619-638.

Giuliano, G. 1995. "The Weakening Transportation-Land Use Connection," *Access*, University of California Transportation Center, 6, 3-11

Haughwout, Andrew F. 1998. "Aggregate Production Functions, Interregional Equilibrium, and the Measurement of Infrastructure Productivity," *Journal of Urban Economics*, 44, 216-227.

Holtz-Eakin, Douglas and Schwartz, Amy E. 1995. "Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways," *International Tax and Public Finance*, 2, 459-468.

Kelejian, Harry H. and Dennis P. Robinson 1997. "Infrastructure productivity estimation and its underlying econometric specifications: A sensitivity analysis," *Papers in Regional Science*, 76, 115-131.

Morrison, Catherine J. and Schwartz, Amy E. 1996. "State Infrastructure and Productive Performance," *The American Economic Review*, 86, 1095-1111.

Munnell, Alicia H. 1992. "Policy Watch: Infrastructure Investment and Economic Growth" *Journal of Economic Perspectives*, 6, 189-98

Rephann, Terance and Isserman, Andrew. 1994. "New Highways as Economic Development Tools: An Evaluation Using Quasi-Experimental Matching Methods," *Regional Science and Urban Economics*, 24, 723-751.

Small, Kenneth A. 1992. *Urban Transportation Economics*, Chur, Switzerland ; New York : Harwood Academic Publishers.

Taylor, Leon. 1992. "Infrastructural Competition Among Jurisdictions," *Journal of Public Economics*, 49, 241-259.

Wilson, John Douglas. 1986. "A Theory of Interregional Tax Competition," *Journal of Urban Economics*, 19, 296-315.

Wildasin, David E. 1988. "Nash Equlibria in Models of Fiscal Competition," *Journal of Public Economics*, 35, 229-240.

Wheaton, William C. 1995. "Competition over Capital Taxation in a Two-region Economy," *MIT Center for Real Estate*, February 1995.

Zodrow, George R. and Peter Mieszkowski. 1986. "Pigou, Tiebout, Property Taxation, and the Underprovision of Local Public Goods," *Journal of Urban Economics*, 19, 356-370.

CHAPTER 3

An Empirical Study of Economic Spillovers of Interstate 105 in Los Angeles County

Given that highways are productive, their investment generates output growth at the place where they are provided. Output expands for two reasons. First, if highway stocks enter production function directly as public inputs, the output will rise with an increase in this variable. This is the subject of intense investigation in the debate on public capital productivity, reviewed in Chapter 2. Second, the spatial equilibrium condition requires that factor prices equality be maintained, leading to factor migration and relocation of business activities into the region of highway investment. The role of highway investment in influencing the location of factors and businesses is relatively under-researched because of the lack of spatial considerations in past studies. The objective of this chapter is to shed light on this aspect of the impact of highway investment.

Researchers argued that given the completed state of national highway network, marginal investment in highways at this point in time would have less impact on the aggregate output (Fernald, 2000) and more on triggering factor migration and relocation of business activities (Boarnet, 1998; Boarnet and Haughwout, 2000). While an increase in factor endowments will raise the level of output locally, the mirror effect of this is factor out-migration from other places. While mobile factors, such as mobile capital and labor, can be relocated to receive higher rents, owners of fixed factors, such as land and buildings, in effected areas lose because they will receive lower rent. Such patterns of factor migration, therefore, may imply negative economic spillovers in areas lagging in highway investment.

Since private factors in a certain impact area must have migrated from or might have been allocated to somewhere else, the unusually rapid factor growth in the impact area reflect factor in-migration there at the cost of out-migration elsewhere. Although we may be unable to identify the place where those factors come from, we do know that they come from somewhere, maybe many places, which collectively can be said to experience negative spillovers.[1] In addition, since it is the factor migration, not the productivity impact of highway, that reflects the economic spillover, most economic spillover literature misses the point by focusing on aggregate output or its proxies, rather than input variables. To shed lights on economic spillovers, it is more appropriate to measure the effect directly through the movement of the factors of production.

An empirical study presented here was built on the current literature on economic spillovers, improving upon its several shortcomings. First of all, the geographic details of most studies are too crude to provide appropriate policy recommendations. Researchers have used state-level data and found no evidence of spillovers.[2] (See, for example, Holtz-Eakin and Schwartz, 1995.) A critical problem with highly aggregate studies is that most infrastructure investment decision is made at a local level. More recently, disaggregate analyses of county-level data invariably uncovered statistically significant negative spillovers (e.g. Rephann and Isserman, 1994). Yet, the detail level of analysis is not

[1] The two-region model in Chapter 3 can be viewed according to this line of reasoning – the region not receiving highway investment can be thought of as an *aggregate* of all areas *outside* the impact area, which collectively experience factor out-migration, even though the absolute out-migration in each individual region may be small. This clearly reflects the external costs of highway investment.

[2] As argued in Chapter 1, this result might stem from the use of inappropriate unit of observations – the state-level data is too crude for analysis of spillovers.

sufficient to inform highway finance in the context of large urbanized areas, where many small local jurisdictions form a regional economy. Therefore, to better inform the highway policy-making process, I improve the spatial aspect of the empirical studies by adopting of a fine-grained level of analysis. Second, as mentioned previously, the measure of economic spillovers in the past literature is often inaccurate – aggregate output variables or their proxies were often used. I use, as discussed in the previous chapter, a more appropriate and direct measure of spillover, i.e. the movement of private factors of production. Third, most previous studies were carried out using data from rural areas (e.g. Chandra and Thompson, 2000). None of the studies examine the economic spillovers in an urban setting, where many large transportation projects take place. To my knowledge, this empirical study is the first to focus exclusively on the fast-growing highly urbanized areas.

3.1 Economic Spillovers Hypothesis

In this section, I use an example of a hypothetical city, shown in Figure 3.1 to illustrate a particular hypothesis of economic spillover. If I assume that the city is homogeneous, in that employment is distributed evenly over the city, it is also reasonable to assume that growth rates of factors of production are uniform over space.[3] Consider locations A, B, and C, which are identical in every aspect under this assumption, in a hypothetical urban area. Locations A and B are located in the same neighborhood, but C is more distant from them. Factor growth rates in all three locations should be similar although they may fluctuate over time with macroeconomic trend. However, this pattern

[3] This assumption is plausible in decentralized cities, but less likely to hold in monocentric ones. It is also approximately correct for businesses in some sectors that tend to scatter uniformly over areas, such as services and retail trade.

of factor growth rates may be interrupted by certain regional shocks, one of which is construction of a new highway.

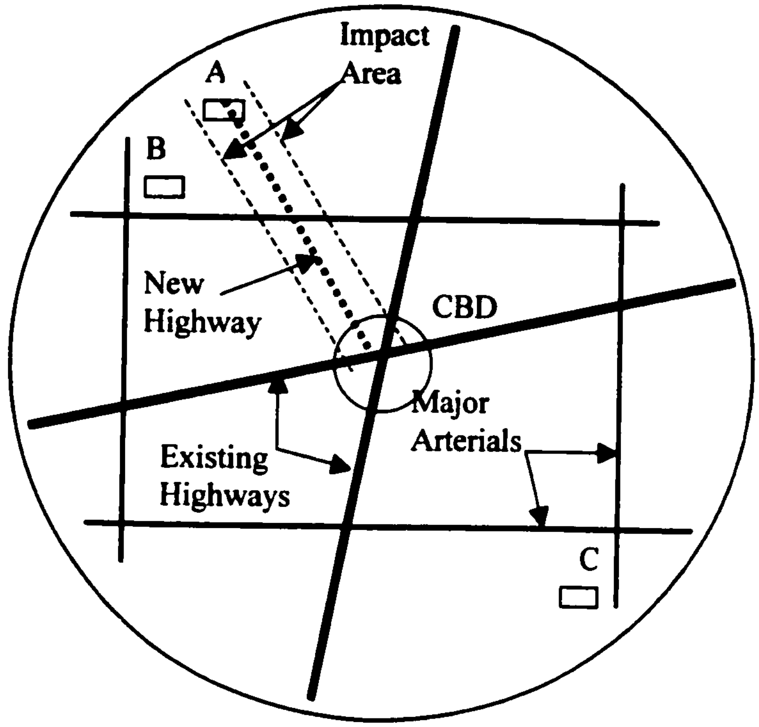


Figure 3.1 A Hypothetical City with a New Highway

Consider a new highway project (dotted line in Figure 3.1). If the economic benefits of the new highway are strictly localized and confined in the highway corridor, factor growth rate in Location A will accelerate and diverge from the regional trend. Factor growth rates in Locations B and C, which are outside the highway corridors, will lag behind. The altered pattern of factor growth rates in these locations may indicate two possible scenarios of economic spillovers.

No Economic Spillovers

The trend of regional factor growth rate is maintained in locations B and C, and only the factor growth rate in location A diverges upward.

Negative Spillovers

The factor growth rate in region A diverges upward, the growth rate in location B downward from the regional trend. The regional growth rate will be maintained in location C.

These patterns of factor growth rates can be used to test the hypothesis of negative spillovers. Let $diff_1$ be the factor growth rate difference between A and B and $diff_2$ be the factor growth rate difference between A and C. The null hypothesis that there is no spillover can be written as:

H_0: $diff_1 = diff_2$

The alternative hypothesis, corresponding to the existence of negative spillovers, can be written as:

H_a: $diff_1 \neq diff_2$

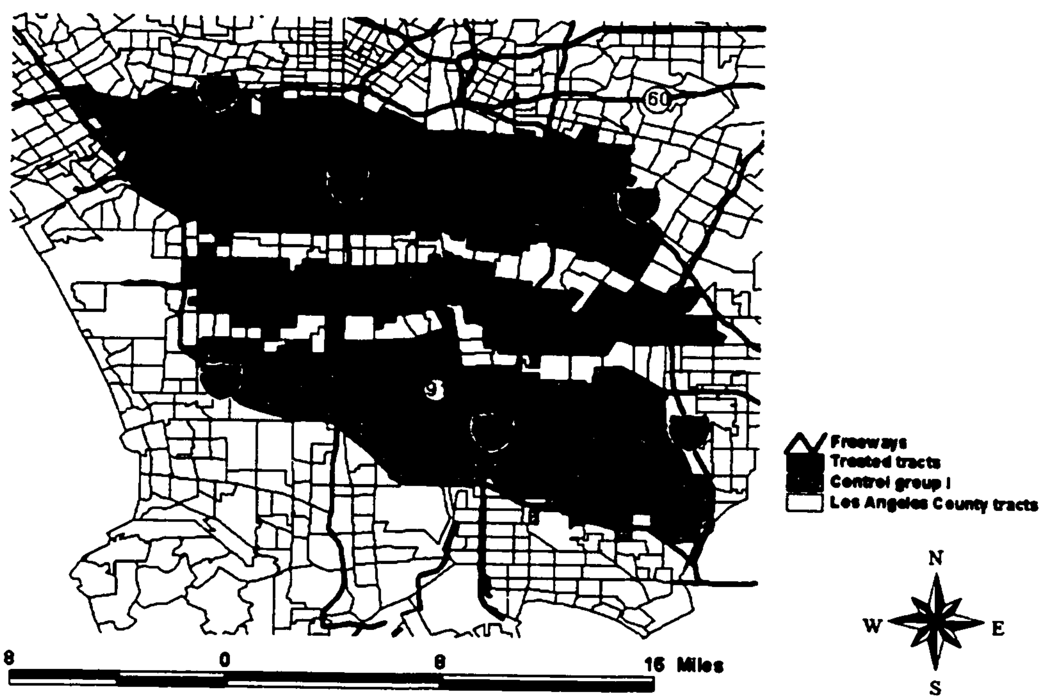
3.2 Empirical Research Design

To examine the hypothesis of economic spillovers, I employed a quasi-experimental approach (Rephann and Isserman, 1994), using data at the *census tract* level. Since data on private factors of production at such a detailed level are severely limited, I was able to acquire only total employment and retail employment in census tracts, and these would be used as measures of spillovers in this research. The treatment in the quasi-experiment is the proximity to a new highway, specifically in this study, the Interstate 105 (Century Freeway), which was opened in 1993. The duration of the quasi-experiment is divided into two periods, the pre-treatment period, between 1980 and 1990, and post-treatment period between 1990 and 1997. After the treated tracts, i.e., tracts that receive treatment, are identified, controls are chosen based on the employment and other characteristics during the pre-treatment period. In this way, I ensured that treated and control tracts are as similar as possible prior to the treatment. The post-treatment data are then analyzed to examine how the treatment affects employment in treated and control tracts after the treatment.

I control the effect of regional economy by limiting the scope of the study in one metropolitan area, i.e., the Los Angeles-Riverside-Orange County, CMSA. The focus of the quasi-experiment study is on the southwestern corner of Los Angeles County, where the Interstate 105 is located and areas northwest and east of downtown Los Angeles. Census tracts in these locations are categorized into three groups, including the treated group, the first control group, and the second control group. The treated group contains all census tracts that would directly benefit from the newly opened highway. These include the tracts whose centroids are within a one-mile distance from the Century Freeway. This definition is based on the hypothesis that the positive employment impact from a highway is strongest within one mile from its centerline. There are 63 tracts that fall in this category, as shown in Figure 3.2.

Two control groups are considered.[4] The first control group, corresponding to locations B in the example in section 3.1, includes census tracts that are located in the same general area as those in the treated tract, i.e., South Central Los Angeles. These tracts are near but not directly along the highway corridor, and might not benefit from the highway in terms of employment, but might be adversely affected by negative spillovers from tracts in the treated group. These control candidates are defined as census tracts that are within the boundary of five Interstate Highways, namely, I-405 to the west, I-10 to the north, I-5 to the northeast, and I-605 to the west, except the treated tracts defined in the previous section. See Figure 3.2.

Figure 3.2 Treated Tracts and The First Control Group



There are several reasons for the definition of this set of control candidates. First, the employment impact of the Interstate 105 (Century Freeway, I-105) is likely to be geographically concentrated, and these surrounding freeways act as a natural bound. The

[4] I will occasionally refer to census tracts in these groups as control candidates.

I-105 lies roughly at the middle of the block of land defined by these freeways. Major employment subcenters are located north and south of this block with approximate equal distance (Downtown Los Angeles and Long Beach). However, no major employment subcenter lies within the block. Finally, the San Diego Freeway (I-405) provides a boundary to any coastal effect from the Pacific Ocean. There are 219 tracts in the first control group.

The second control group, corresponding to locations C in section 3.1, includes census tracts that are in the same regional economy as those in the treated and the first control groups, but are significantly distant, greater than ten miles, from the centerline of the new highway. Under the spillover hypothesis described above, the highway is sufficiently distant from these locations that it does not exert any positive or negative employment impacts on them. These census tracts are located within Los Angeles County, specifically in San Gabriel and San Fernando Valleys, as shown in Figure 3.3. There are 333 tracts that fall in this category.

Since census tracts in both control groups may vary widely in terms of employment growth, industrial compositions, socio-demographic characteristics of residents, land and property values, and other characteristics, they may not be appropriate controls for the tracts in the treated group. It is therefore necessary to select, from the pool of these control candidates, tracts that are most similar to those in the treated group. To ensure that the selection of controls is acceptable, i.e., the characteristics of controls are similar to those of treated tracts for which they are selected, statistical tests of the Null hypothesis that the average treated-control-pair difference is zero are performed. Let *ADTC1* be the average of treated-control-matched-pair difference between the treated and first control group, *ADTC2* be the average of treated-control-matched-pair difference between the treated and second control group, and *AC2C1* be the average of the matched-pair difference between the two control groups. To evaluate the selection of controls, statistical tests of the following hypothesis are performed in the pre-treatment period.

$\mathbf{H_0}$: $ADTC1 = 0$ *and* $ADTC2 = 0$ *and* $AC2C1 = 0$

$\mathbf{H_a}$: $ADTC1 \neq 0$ *or* $ADTC2 \neq 0$ *or* $AC2C1 \neq 0$

Failures to reject the Null in the pre-treatment period indicate that the selected controls are, on average, appropriate for the treated tracts, and can be used to test the spillover hypothesis in the post-treatment period. Note that the technical details of the control selection process (census tract matching and evaluation) will be discussed in Sections 3.3 and 3.4.

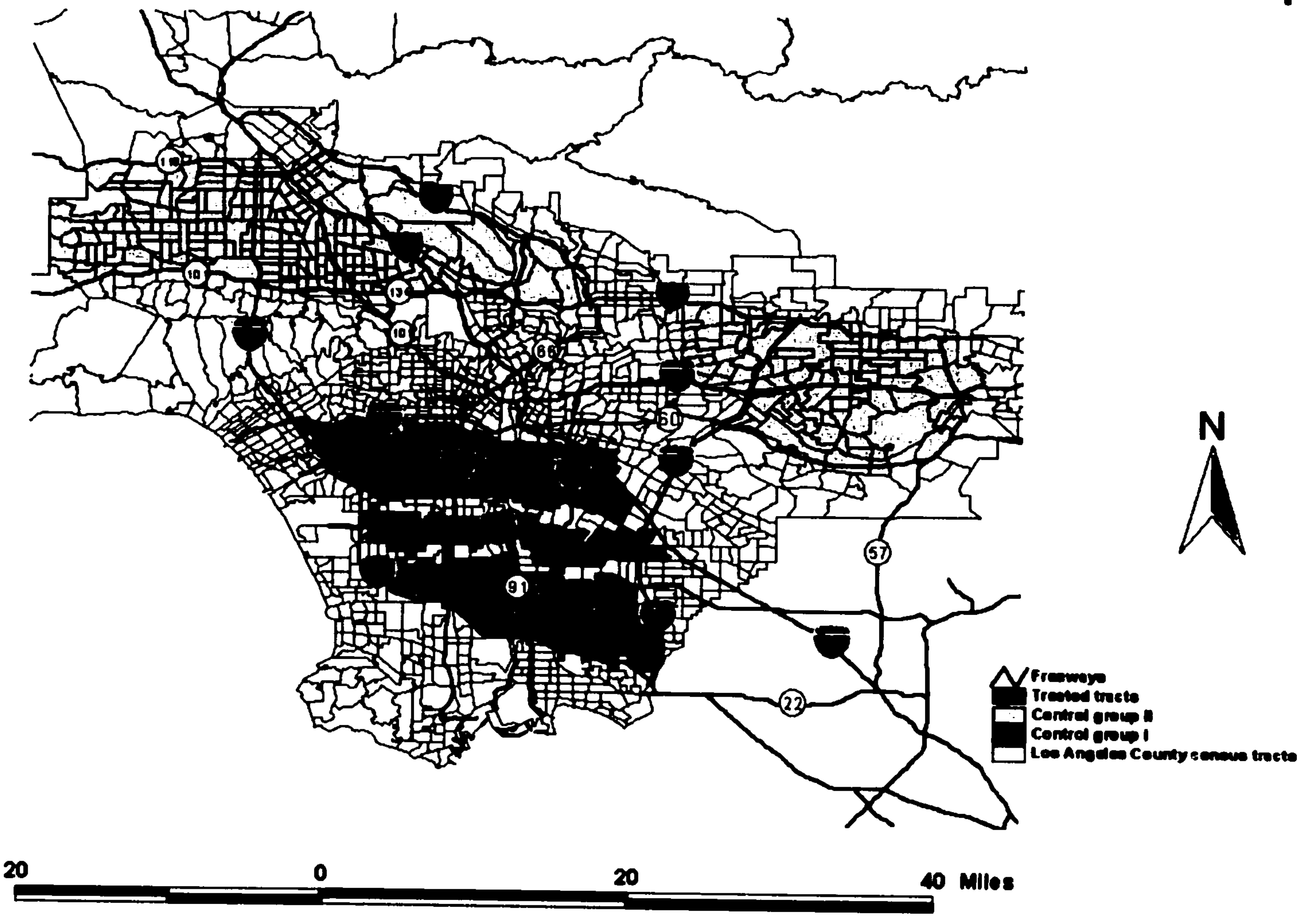
The spillover hypotheses described in section 3.1 are equivalent to the following hypotheses.

$\mathbf{H_0}$: $ADTC1 > 0$ *and* $ADTC2 > 0$ *and* $AC2C1 = 0$

$\mathbf{H_a}$: $ADTC1 > 0$ *and* $ADTC2 > 0$ *and* $AC2C1 > 0$

These can be verbally stated as follow. If the negative spillovers are not significant ($\mathbf{H_0}$), we will expect no difference in the growth rates of factors in the two control groups, but the rates are still highest in the treated group. If the new highway exerts negative spillovers ($\mathbf{H_a}$), we will expect the growth rates of private factors in the treated group to be highest, followed by the second control group, and then the first control group.

Figure 3.3 I-105 Treated Tracts, The First, and The Second Control Gruoups



3.3 Census Tract Matching

For each treated census tract, a control tract must be selected. An ideal control tract would be identical to a treated tract in every aspect. This, however, is not possible, and a control tract must instead be chosen from a pool of potential control candidates in such a way that all its relevant characteristics match with those of the treated tract as closely as possible. The process of control tract selection is called census tract matching, and the characteristics, by which control tracts are selected, are called matching characteristics.[5] I followed Rephann and Isserman's matching approach, which involves the ranking of Mahalanobis distances. Rephann and Isserman, however, did not take up the issue of how matching characteristics are chosen, and how that might affect the matching results. I refined their matching process by using several different specifications of matching characteristics and examining how they affect matching results, and more importantly results of hypothesis tests.

3.3.1 Mahalanobis Distances and Matching Characteristics

To choose an optimal control, all tracts in the pool of control candidates can be ranked based on their similarity to a given treated tract. This similarity can be measured by the Mahalanobis distance between a pair of treated and control tracts as given by:

$$\mathbf{MD}(\mathbf{X}_T, \mathbf{X}_i) = (\mathbf{X}_T - \mathbf{X}_i)'\mathbf{R}^{-1}(\mathbf{X}_T - \mathbf{X}_i) \tag{3.1}$$

where $\mathbf{MD}(\mathbf{X}_T, \mathbf{X}_i)$ is the vector of Mahalanobis distances; $\mathbf{X}_T$ and $\mathbf{X}_i$ are the vectors of matching characteristics for a treated census tract T and an untreated census tract i, respectively; $\mathbf{R}$ is the variance-covariance matrix of the variables for all control candidates. Since the unit of measurement of each variable differs, the variance-covariance matrix is used to normalize the variables into a single comparable scale. The variance-covariance matrix also reflects the weight given to each matching characteristic. This allows trade-off among selection criteria. Also, note that Mahalanobis distances can be constructed from different sets (specifications) of matching characteristics, each of which will produce different values of Mahalanobis distances, and hence different matching results.

Table 3.1 Matching Characteristics

Category	Variables
Socio-economic characteristics	
Population	**Population growth rate**
	Population density
	Racial composition
	Education
Employment	**Employment growth rate**
	Employment density
Income	Per capita income
	Median income
Industrial composition	**Employment growth rate by industry**
	Fraction of employment by industry
Potential for growth	
Land use composition	Residential share
	Amount of land by type of use
Others	Median rent
	Median property value
	Housing age
Other amenities	Coastal distance
	Presence of nearby freeway

Matching characteristics are used to control various characteristics of census tracts. To specify these variables, I consider the relevance of characteristics that influence

[5] I also refer to matching characteristics as selection variables and matching criteria interchangeably all through this chapter.

economic variables of census tracts. For example, socio-economic characteristics of the population, land use, zoning regulation, industrial composition, quality of other public service and infrastructure, and geographical characteristics, and etc. are all relevant to growth potential in any census tract. Potential matching characteristics are listed in Table 3.1.

Three of the variables listed in Table 3.1, in boldface, are considered key matching characteristics, namely population growth rate, employment growth rate, and retail employment growth rate. Since these variables are to be used for testing spillover hypothesis in the post-treatment period, they are included in all specifications of matching characteristics in the pre-treatment period. The first two variables are major indicators of the stage of urban development. Newly urbanized areas, for example, tend to experience population growth, and gradually followed by employment growth. Areas with very fast population growth rates may be less likely to experience high employment growth rate in the near future. These growths are, of course, subject to other factors, such as amount of developable land, land use and zoning regulation, as well as land price. Other factors that may affect employment growth include availability of labor, labor costs, proximity to transportation and other kinds of infrastructure, etc. However, since different types of employers require different kinds of skilled labor and infrastructure, the ideal matching characteristics should include employment by industry. Only data on retail employment is available, however, and is used as a key selection variable.

All key selection variables are in the form of growth rate. Other selection variables are in the form of level. For example, as an indicator for potential growth, the median value of properties itself, may better reflect this potential than may the rate of change in median property value in the past ten years. Similar reasoning applies to variables, such as amount of developable land, pool of non-skilled labor (e.g. persons without high-school diplomas), etc. Hence, the data at the end of pre-treatment period are used for these selection variables.

3.3.2 Data

Two types of data for census tract matching include numerical and geographical data. I obtained employment data (1980, 1990, and 1997) for census tracts in the five-county Los Angeles Metropolitan Area from the Southern California Association of Governments (SCAG). Other data were obtained from the U.S. Bureau of Census' 1980 and 1990 Census of Population and Housing. Summary statistics of these data are provided in Tables 3.2 and 3.3. As for geographical data, such as an alignment of the Century Freeway and census tract boundaries, I used the data from a CD-ROM[6] provided by Environmental Systems Research Institute, Inc. (ESRI).

Table 3.2 Summary Statistics of Tract Employment, Retail Employment, and Population in Los Angeles County in 1980, 1990, and 1997

Variables	Employment			Retail Employment			Population		
Year	1980	1990	1997	1980	1990	1997	1980	1990	1997
Tract Mean	2,396.48	2,793.87	2,622.90	338.65	438.54	400.14	4,548.35	5,365.11	5,805.36
Standard Deviation	4,345.84	4,822.88	4,901.04	532.62	564.97	586.66	2,053.73	2,534.15	2,957.92
Mininum	0	0	17	0	0	0	0	0	0
Maximum	61,788	70,966	83,847	9,244	7,293	6,034	15,048	28,770	31,791
Number of Observations	1,644	1,652	1,642	1,644	1,652	1,642	1,644	1,652	1,642
LA County Total	3,939,815	4,615,474	4,306,794	556,734	724,467	657,031	7,477,489	8,863,164	9,538,203

[6] I used a copy of ESRI Data and Maps CD-ROM owned by the UCI Institute of Transportation Studies.

Table 3.3 Summary Statistics of Selected Census Variables in Los Angeles County in 1990

	Tract Mean	Standard Deviation	Mininum	Maximum	Number of Observations
Population	5365.11	2537.32	0	28792	1652
Employment	2793.87	4822.88	0	70966	1652
Retail employment	438.54	564.97	0	7293	1652
Tract land area (sq. mi.)	2.4413	16.9144	0.0001	371.7888	1652
Population density (persons/sq. mi.)	55953.76	1767061.67	0.00	71822222.20	1652
Employment density (jobs/sq. mi.)	5041.21	10885.89	0	230401.61	1652
Retail employment density (jobs/sq. mi.)	854.83	1355.00	0	25743.03	1652
Fraction of Black population	0.1162	0.2005	0	0.9473	1652
Fraction of Hispanic population	0.3449	0.2714	0	1	1652
Median household income ($)	38015.85	18884.05	0.00	150001.00	1652
Per capita income ($)	17320.01	12186.19	0.00	107694.00	1652
Fraction of persons with college degree	0.1769	0.1036	0	0.6667	1652
Fraction of persons lacking H.S. diploma	0.0970	0.0750	0	0.6429	1652
Median value of property ($)	240492.26	116423.04	0.00	500001.00	1652
Median rent ($)	623	185.59	0	1001	1652

The definition of census tract boundaries changes over time. Three types of changes include tract merging, tract splitting, and tract redefinition. Tract merging involves merging two or more 1980 tracts into one 1990. This is common in mature urban areas or areas with declining population, such as South Central Los Angeles. In fast growing areas, such as the southern part of Orange County, rapid population growth led to the splitting of a very large tract by 1980 definition to two or more smaller 1990 tracts. Tract redefinition involves both merging and splitting or simply redrawing new tract boundaries.

In order to make any comparison between 1980 and 1990 data, it is necessary to choose a unit of observation, i.e. either 1980 or 1990 tract definitions. Regardless of which year of tract definition is chosen, some adjustments[7] of the data with regards to changing tract boundaries are needed. These adjustments are discussed in more detail in the Appendix A.3. In this case study, due to few cases of tract splitting and several cases of merging, the 1990 tract definition is chosen as the unit of observation.

3.3.3 Choosing Controls: Minimum-Distance Controls, Optimal Matching, and Outliers

For any given treated tract, a Mahalanobis distance can be computed for each potential control candidate. These distances are then ranked, and the control candidate with a minimum distance[8] is assigned as an optimal control to that treated tract. There are two problems that might arise from this type of assignment.

3.3.3.1 Non-unique Matched Pairs

The problem occurs when two or more treated tracts share the same minimum-distance control. Rephann and Isserman solved this problem by employing an optimal matching method to choose an optimal control. The method assigns a control to each treated tract in a way that minimizes the total Mahalanobis distance. The optimal matching was shown by Rosenbaum (1989) to be equivalent to a network flow problem, and can therefore be formulated as a linear program. Linear optimization software, such as LINDO can be used to solve the optimal matching problem.

In this case study, the severity of the problem of non-unique matched pairs varies depending on matching specifications[9], the sets of criteria upon which the control selection is based. Some specifications produce a large number of unique matched pairs

---

[7] These adjustments are based on information provided by the U.S. Census Bureau's Table A: Census Tract Comparability: 1990 to 1980 Census Tracts and Block Numbering Areas IV Los Angeles-Long Beach, CA PMSA in the 1990 Census of Population and Housing.

[8] This is the one that is most similar to the treated tract according to the matching criteria used to compute the Mahalanobis distance.

[9] See section 3.4 for details.

(40 pairs or more), and few non-unique ones.[10] Other specifications produce a majority of non-unique matched pairs and few unique ones. The hypothesis tests, discussed in section 3.2, require unique matched pairs in order to calculate the average of pair-by-matched pair differences. Therefore, in the cases where most of the matched pairs are unique, the problem of non-unique matched pairs poses little trouble for the hypothesis tests because there are a large number of unique matched pairs to begin with. The tests can be carried out simply by excluding non-unique and non-minimum-distanced matched pairs. For example, if three treated tracts share one control, only the treated tract that is the most similar to that control, i.e., the one with the minimum Mahalanobis distance to the control, will be included, and the other two treated tracts will be excluded. On the other hand, in the cases where most of the matched pairs are non-unique, the problem must be addressed directly by the optimal matching approach, mentioned above. For a detailed discussion of this approach, see Rosenbaum (1989).

3.3.3.2 Outliers

In few cases, certain characteristics of treated tracts take very extreme values. Consequently, even a minimum-distance control tract can still be significantly different from them. A signal for this is a large value of the Mahalanobis distance. In the literature on pattern-recognition[11], a distance of 10 is often used as a cutoff. Any observation with the distance greater than 10 is ruled out from belonging to the group. Based on this cutoff, some treated tracts were identified as outliers, and excluded from further analysis.

---

[10] This could happen under two circumstances. First, treated tracts may differ substantially from one another, and therefore their best controls are by construction different. Second, there may be a large number of control candidates with wide variation in matching characteristics. This increases the likelihood of a unique control being found for each treated tract.

[11] See Taguchi, et al. (2001), for example.

3.4 Matching Evaluation: Pre-treatment Tests

Student *t*-test and Hotelling's *F*-test[12] are performed to assess matching quality. The *t*-test is run on each individual matching characteristic, and the Hotelling's is used to test joint hypotheses. Two versions of Null hypotheses can be tested. The first is to test the hypothesis that the difference between *group* mean is zero, and the second that the average of *pair-by-matched-pair* difference is zero. The latter is a more powerful version of the tests because it takes into account information provided by each individually matched pair. Both versions of the null can be tested between each pair of groups, between the treated and the first control group, between the treated and the second control group, and between the two control groups.

To illustrate, the hypothesis tests of characteristic x between the two groups, denoted by subscripts, T and C, are discussed. Note these tests can be applied to any pair of groups of census tracts, as mentioned above. Let $\bar{x}_T^0$ and $\bar{x}_C^0$ be the sample mean of pre-treatment characteristic x, in the treated and control group, respectively. The weaker version of Null and alternative hypotheses can be written as:

$$\mathrm{H}_0 : \bar{x}_T^0 = \bar{x}_C^0$$

$$\mathrm{H}_a : \bar{x}_T^0 \neq \bar{x}_C^0$$

Under the Null, the test statistic t is:

$$t_{n_T+n_C-2} = \frac{\bar{x}_T^0 - \bar{x}_C^0}{\sqrt{\frac{(n_T-1)s_{xT}^2 + (n_C-1)s_{xC}^2}{n_T+n_C-2} \cdot \left(\frac{1}{n_T} + \frac{1}{n_C}\right)}} \qquad (3.2)$$

[12] An important underlying assumption on which these tests are based is that census tracts in treated and control group are randomly chosen from two identically and independently normal populations with unknown variance. Since treated tracts and controls are located in a relatively small and similar area, such

where

n_T and n_C = number of treated and control tracts, respectively, and

s^2_{xT} and s^2_{xC} = sample variance of characteristic i in the treated and control groups.

Note that this version of the test does not require pair-by-matched pair difference to be computed, and hence the number of tracts in the two groups may not be the same. In a specific case where the number of treated tracts and controls are the same, the test statistic is reduced to:

$$t_{2n-2} = \frac{\bar{x}^0_T - \bar{x}^0_C}{\sqrt{\frac{s^2_{xT} + s^2_{xC}}{n}}} \qquad (3.3)$$

where n = number of treated tracts (or controls.)

Under the Null, this test statistic follows the t distribution with $2n-2$ degrees of freedom. Note that when n is large, the test statistic may be approximately normal.

Now let $\overline{dx}^0_{TC} = \sum_{i=1}^{n} \frac{x^0_{Ti} - x^0_{Ci}}{n}$. This is a pre-treatment average pair-by-matched-pair difference between each treated tract and its control. The more powerful version of the hypotheses is given by:

$H_0 : \overline{dx}^0_{TC} = 0$

$H_a : \overline{dx}^0_{TC} \neq 0$

As mentioned earlier, the number of tracts, n, in each control group must be the same in this case. Under the Null, the test statistic is

---

assumption may be approximately correct. Also, the likelihood of being treated (being close to a new highway) may be approximately uniform.

$$t_{n-1} = \frac{\overline{dx_{TC}^{0}}}{\sqrt{\frac{s^2_{dx^0_{TC}}}{n-1}}} \tag{3.4}$$

The statistic follows the t distribution with $n\text{-}1$ degrees of freedom, and when n is large, it is approximately normal. In both versions of the test, the p-value – the probability that the Null is true, which can be determined from the statistics, is an indicator of matching quality. If the p-value is large, the matches are good with respect to that characteristic. On the other hand, if the p-value is very low, then the matches are poor because the test indicates that the difference in the two means are highly likely to be real.

Note that the nominator in equation (3.3), the mean of pair-by-matched-pair differences, can be rewritten as the difference between group mean, that is the nominator in equation (3.4). The "mean difference" can therefore be determined either way. However, the t-statistics, reported in the section 3.5, are determined from the more powerful version of tests, i.e. equation (3.4)

The Hotelling's test is a multivariate version of the t-test. The null hypothesis is that the differences in the means of all characteristics are jointly zeros. The null and alternative hypotheses can be written formally as:

$$\mathrm{H}_0 : \overline{\mathbf{X}}_\mathrm{T} - \overline{\mathbf{X}}_\mathrm{C} = \mathbf{0}$$

$$\mathrm{H}_\mathrm{a} : \overline{\mathbf{X}}_\mathrm{T} - \overline{\mathbf{X}}_\mathrm{C} \neq \mathbf{0}$$

where $\overline{\mathbf{X}}_\mathrm{T}$ and $\overline{\mathbf{X}}_\mathrm{C}$ are a $1 \times k$ vector of the k mean characteristics of treated and control tracts, respectively. Let **S** be the estimated covariance matrix of these characteristics. The Hotelling's T^2 statistic can be written as:

$$T^2 = (\overline{\mathbf{X}}_\mathrm{T} - \overline{\mathbf{X}}_\mathrm{C})\mathbf{S}^{-1}(\overline{\mathbf{X}}_\mathrm{T} - \overline{\mathbf{X}}_\mathrm{C})' \tag{3.5}$$

An F-statistic can be computed from the Hotelling's T^2:

$$F = \frac{T^2 / k}{(n-1)/(n-k)} \tag{3.6}$$

This statistic follows an F-distribution with k and $(n - k)$ degrees of freedom. Like the t-test, the p-value from the F-test can be an indicator of matching quality. Together, these two tests form the basis for evaluation of matching quality in the pre-treatment period. In this study, acceptable matches are defined as those with p-values from all hypothesis tests greater than 0.10. Various specifications of matching characteristics are evaluated with these pre-treatment tests and the post-treatment results are reported in the next section.

3.5 Results

3.5.1 Matching Results and Evaluation: Basic Specification

In this section, detailed matching results and evaluation of the basic specification are discussed.[13] The basic specification posits that only the trends in the past of the three key characteristics of tracts employment, retail employment, and population are sufficient to control for growth potential in the future, and therefore includes only three matching characteristics: employment, retail employment and population growth rates between 1980 and 1990. Between the treated and the first control group, there are 15 non-unique matched pairs (with shared controls) and two outliers. Between the treated and the second control group, there are 20 non-unique matched pairs and also two outliers. After the optimal matching technique is used to reassign non-uniquely matched controls, there are 57 uniquely matched pairs between each pair of census tract groups. A summary of statistics of various characteristics of matched tracts in the three census tract groups is

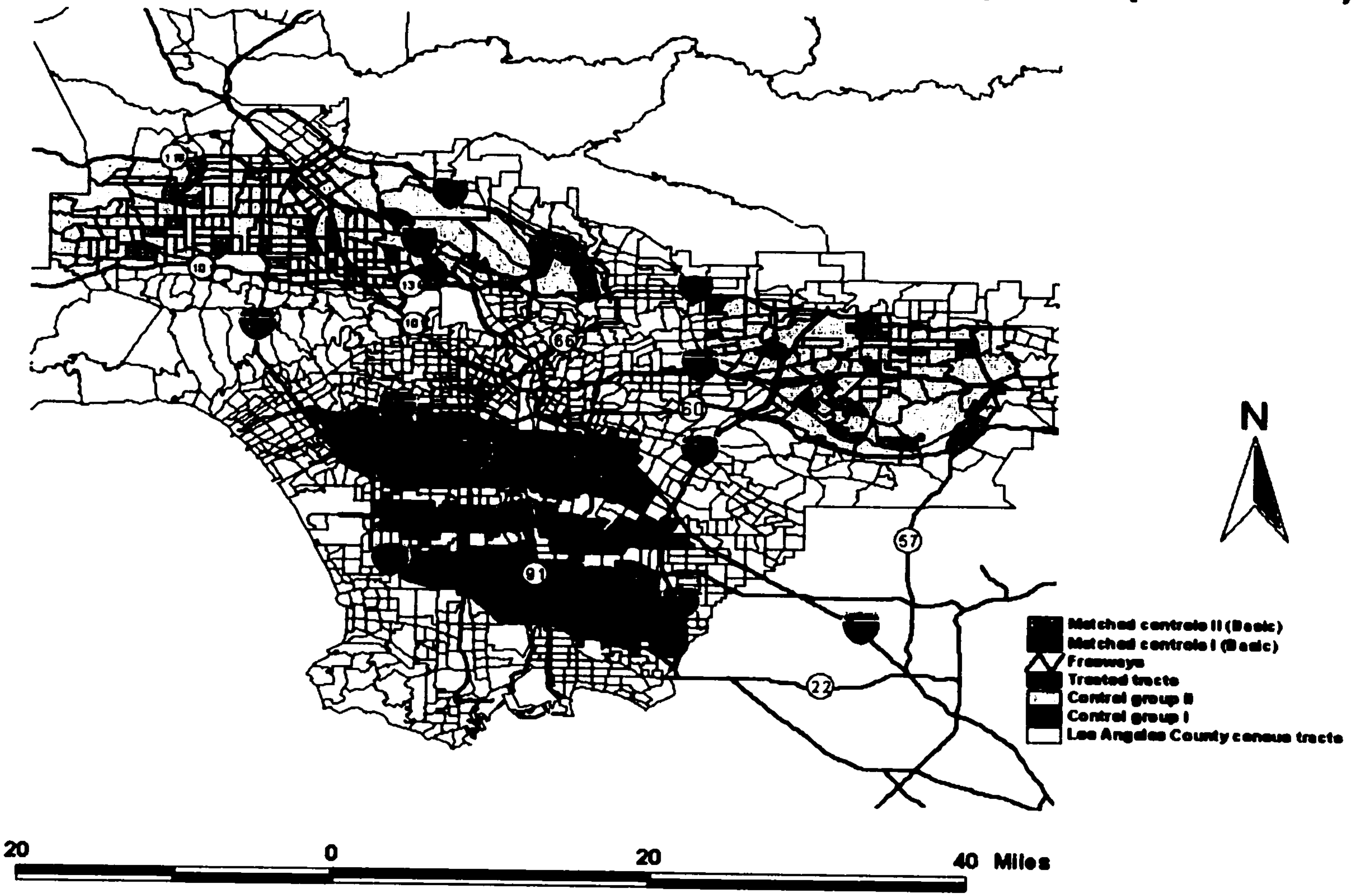
[13] Full results of other specifications are the product of the same procedures, and will not be repeated here, but are available upon request.

provided in Table 3.4. Treated tracts and their matched controls are also shown in Figure 3.4. The full pair-by-matched-pair results of this and other specifications are available upon request.

Table 3.4 Summary of Census Tract Characteristics: Basic Specification

Basic Specification	Treated Tracts		Control I		Control II	
Census Tract Characteristics	Mean	S.E.	Mean	S.E.	Mean	S.E.
Employment growth rate, 1990-1980 (%)	26.16	1.16	28.10	1.32	28.73	1.03
Retail employment growth rate, 1990-1980 (%)	119.35	3.52	112.59	3.17	117.91	3.40
Population growth rate, 1990-1980 (%)	12.96	0.30	13.05	0.29	13.89	0.27
Fraction of retail employment, 1990	0.2143	0.0023	0.2288	0.0023	0.2142	0.0024
Employment density, 1990 (jobs/sq.mi.)	2823	38.55	4932	92.68	3019	46.77
Population density, 1990 (persons/sq.mi.)	12605	94.03	13000	136.10	7379	60.80
Fraction of Black population	0.3622	0.0053	0.2262	0.0047	0.0345	0.0005
Fraction of Hispanic population	0.4652	0.0041	0.3592	0.0052	0.3201	0.0040
Median household income ($)	28826	158.05	30659	203.00	42704	265.55
Per capita income ($)	9436	64.45	13455	126.75	18205	157.57
Fraction of college graduate	0.0301	0.0004	0.0687	0.0011	0.1046	0.0011
Fraction of persons lacking High school diploma	0.4994	0.0010	0.5067	0.0018	0.4196	0.0013
Median value of property ($)	140139	703.57	198204	1619.45	254949	1845.44
Median rent ($)	501	1.82	554	2.19	667	2.34
Employment growth rate, 1997-1990 (%)	208.64	7.39	13.06	2.59	172.77	9.95
Retail employment growth rate, 1997-1990 (%)	234.97	8.63	35.91	3.11	165.60	8.03
Population growth rate, 1997-1990 (%)	9.06	0.33	68.84	8.64	5.00	0.19
Number of observations	57		57		57	

Figure 3.4 I-105 Treated Tracts and Matched Controls (Basic Specification)



Pre-treatment t-tests for matching characteristics in the basic specification are performed on the differences between each pair of census tract groups, namely the treated and first control groups, the treated and second control groups, and the first and second control groups, and are summarized in Table 3.5. These tests are based on the t-statistics determined by equation (3.4). As can be seen in the first two panels of Table 3.5, the mean of pair-by-matched-pair differences of the three matching characteristics range from −1.94% to 6.77%. The t-test results, determined by equation (3.4), suggest that the Null hypothesis that the mean differences between treated and the two control groups are zero cannot be rejected for all three matching characteristics. All p-values are greater than 0.20, except for the mean difference in population growth rate between the treated and the second control group. In the third column, which corresponds to the differences between the two control groups, the t-tests also show that the Null hypothesis cannot be rejected in all three matching characteristics. In addition, the Hotelling's F-tests, as shown at the bottom of Table 3.5, suggest that the joint hypothesis for the three matching characteristics cannot be rejected in all three pairs of census tract groups. These test results show that the control tracts in each group are appropriate for the quasi-experiment, based on the basic matching criteria.

Table 3.5 Pre-Treatment Results: Basic Specification

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Matching characteristics									
Employment growth rate, 1990-1980 (%)	-1.94	-0.5519	0.5832	-2.57	-1.0024	0.3205	0.63	0.1437	0.8863
Retail employment growth rate, 1990-1980 (%)	6.77	1.2204	0.2274	1.44	0.2368	0.8137	5.32	0.9299	0.3564
Population growth rate, 1990-1980 (%)	-0.09	-0.1220	0.9034	-0.93	-1.3731	0.1752	0.84	0.8816	0.3818
Other characteristics									
Fraction of retail employment, 1990	-0.01	-0.5853	0.5607	0.00	0.0005	0.9996	-0.01	-0.6693	0.5061
Employment density, 1990 (jobs/sq.mi.)	-2109	-2.9160	0.0051	-196	-0.4698	0.6403	-1913	-2.4097	0.0193
Population density, 1990 (persons/sq.mi.)	-396	-0.3634	0.7176	5226	7.6167	0.0000	-5621	-5.7144	0.0000
Fraction of Black population	0.14	2.4348	0.0181	0.33	7.9787	0.0000	-0.19	-5.5264	0.0000
Fraction of Hispanic population	0.11	2.5917	0.0122	0.15	4.2663	0.0001	-0.04	-0.9847	0.3290
Median household income ($)	-1832	-0.9925	0.3252	-13878	-7.1079	0.0000	12046	5.7398	0.0000
Per capita income ($)	-4019	-4.0515	0.0002	-8769	-7.8575	0.0000	4750	3.8998	0.0003
Fraction of college graduate	-0.04	-4.6472	0.0000	-0.07	-9.4326	0.0000	0.04	3.4718	0.0010
Fraction of persons lacking High school diploma	-0.01	-0.4683	0.6414	0.08	7.2488	0.0000	-0.09	-5.0585	0.0000
Median value of property ($)	-58065	-4.2974	0.0001	-114811	-7.5676	0.0000	56746	3.0690	0.0033
Median rent ($)	-52.86	-2.6782	0.0097	-165.93	-6.9223	0.0000	113.07	4.9786	0.0000
Number of observations	57			57			57		
One-group Hotelling T2	2.6044			3.6930			1.6833		
F(3, 54)	0.8371			1.1871			0.5411		
Prob > F(3, 54)	0.4794			0.3233			0.6562		

Note: The t-statistics are determined by equation (3.4).

Table 3.6 Post-Treatment Results: Basic Specification

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Employment growth rate, 1997-1990 (%)	**195.58**	**3.2548**	**0.0019**	35.88	0.3627	0.7182	**159.71**	**2.3763**	**0.0209**
Retail employment growth rate, 1997-1990 (%)	**199.06**	**2.9536**	**0.0046**	69.37	0.7694	0.4449	**129.69**	**2.0839**	**0.0417**
Population growth rate, 1997-1990 (%)	-59.77	-0.9205	0.3612	4.06	1.4263	0.1593	-63.83	-0.9756	0.3335

Note: The t-statistics are determined by the modified version of equation (3.4), which corresponds to the post-treatment period.

Table 3.5 also shows statistics of other characteristics that are not used as matching criteria. Not surprisingly, the *t*-tests reveal statistically significant differences between each pair of census tract groups in some of these characteristics. Since census tracts in the treated group and the first control group are in the same general area, the differences tend to be small and insignificant in several variables, such as population density, education level of residents, and median income. However, census tracts in the second control group are in another very different neighborhood, whose characteristics are very different from those of the treated groups, as reflected by *t*-test results. Thus, it is necessary to modify the matching specification to control for such differences. The results from these alternative specifications are reported in section 3.5.3.

3.5.2 Post-treatment Tests: Basic Matching Specification

To test the spillover hypothesis, the *t*-tests are performed on the mean of pair-by-matched-pair differences in three key characteristics, i.e., employment, retail employment, and population growth rates in the post-treatment period (1990-1997). The post-treatment *t*-statistics are determined by a modified version of equation (3.4), in which the superscript "0", that indicates pre-treatment is changed to a superscript "1" that indicates post-treatment. Note that the modified version of equation (3.4) is used in all post-treatment statistical tests that are reported in this Chapter.

The results of the post-treatment *t*-tests for the basic matching specification are reported in Table 3.6. As can be seen, the mean differences in employment and retail employment growth rates between the treated and both control groups increase significantly. In particular, the mean differences in employment and retail employment growth rates between the treated and the first control group increase from less than 10%

in the pre-treatment period to nearly 200% in the post-treatment period. These differences are also highly statistically significant, at a 1-percent significant level. The second panel of Table 3.6 shows that although the differences between the treated and the second control group increase from the pre-treatment period, they are smaller and statistically insignificant. Finally, the third panel shows that the mean differences between the two control groups are statistically significant at a 5-percent significant level, with the growth rates in the second control group far exceeding those in the first control group by more than 100%. In other words, these empirical results reveal that the employment and retail employment growth rates of census tracts in the treated group – those along the Interstate 105 – are indeed faster than are those in the two control groups, which are more distant from the highway. In addition, census tracts in the second control group – the more distant of the two control groups – grow substantially more rapidly than do those in the first control group *after* the treatment. These empirical results are consistent with the negative spillover hypothesis that the factor growth rate is fastest in the treated tracts along the new highway, slowest in the first control group, which is near but not immediately adjacent to the highway, with the second control group, the most distant from the highway, being in the middle.

3.5.3 Results of Other Matching Specifications

To improve upon matching quality of the basic specifications and to test the robustness of the results from the basic specification, other matching specifications are used.[14] The first alternative specification, matching specification # 1, includes the 1990 fraction of retail employment[15] in addition to the three basic matching variables. This

[14] See a detailed discussion about how various matching specifications are chosen in the Appendix D.
[15] This is the only industry-specific variable with available data at the census tract level.

variable, although admittedly less than ideal, but the only one available at this level of detail, is used to control for sectoral composition in each census tract. In Table 3.7, the pre-treatment results are reported. None of the t-tests can reject the Null hypotheses of the four matching characteristics, nor can the F-tests reject the joint hypotheses. Table 3.8 shows the post-treatment t-test results, which display the same general pattern of growths to the results from the basic specification. The differences in employment and retail employment growth rates between the treated and the first control groups are statistically positive at a 5-percent significant level, with magnitudes that are similar to those of the basic specifications. A distinct exception of this is that the employment growth rate of the second control group exceeds that of the treated group although the mean difference is small and statistically insignificant. Finally, the post-treatment mean differences in employment and retail growth rates between the first and the second control groups are large and statistically significant at a 5- and 10-percent significant level, respectively. The magnitudes of the differences are also similar to the results of the basic specification. Although these results fail to confirm one of the two parts of the spillover hypothesis, i.e. the employment growth rates of the treated and the second control group seems to be similar after the treatment, the fact that the first control group lags after the second control group still provides some evidence that confirms the spillover hypothesis.

In Table 3.9, the results from matching specification #5 are reported. This specification includes employment density in 1990 to control for the potential for future employment growth. As shown by the t-test and F-test results, matching qualities are satisfactory for both control groups as far as matching variables are concerned. Several t-tests for other variables, however, still reject the Null hypotheses, notably, of the differences between the treated and the second control group. The post-treatment results in Table 3.10 show similar pattern of employment growths as those of specification #1. The mean differences in employment and retail employment growth rates between the treated and the first control group are approximately 130%, smaller than are those of the previous two specifications, but statistically significant at a 5- and 10-percent significant level, respectively. The patterns of differences in employment and retail employment growth rates between the treated and the second control groups are very similar, both in terms of magnitudes and statistical significance, to the results of specification #1. As for the differences between the two control groups, the difference in employment growth rates is positive significant at a 10-percent significant level, with the magnitude smaller than those of the previous two specifications. The difference in retail employment growth rates is positive, but is much smaller and statistically insignificant.

Table 3.11 shows the results for matching specification #9. This specification is similar to specification #5, but also includes a variable that reflects demographic composition of census tracts, i.e. the fraction of Hispanic population in 1990. The pre-treatment t-test and F-test results show satisfactory matching quality for all matching criteria, individually and jointly, in all pairs of census tract groups. Table 3.12 shows the post-treatment t-test results for this specification, which reveal growth patterns that resemble those of the basic specification, with an exception of an insignificant difference in retail employment growth rates between the two control group. The magnitudes of the differences are also less extreme, than are those of the basic specification. In any case, the results again provide evidence that confirms the spillover hypothesis.

Table 3.13 shows the results for matching specification #10. This specification not only includes all matching characteristics in specification #5, but also a variable that reflects education level of the residents, i.e. fraction of population lacking a High School diploma. Like the results of the previous specifications, the pre-treatment tests reveal satisfactory matching quality in all matching criteria, individually and jointly, although the *t*-tests for all other variables in the second control group reject the Null hypotheses at a high level of significance. The post-treatment results, shown in Table 3.14, however, show a different pattern of growth rates, specifically between the treated and the second control groups – the mean differences in employment and retail employment growth rates between the two groups are very large in magnitudes and highly statistically significant. Unlike those of the basic specification, these mean differences between the treated and the second control groups are also positive and statistically significant. However, because of the large magnitude of the differences in employment growth rates between the treated and the first control group, the differences between the two control are statistically significant at a 1-percent significant level, with a smaller magnitude than are those from previous specifications. The difference in retail employment growth rates between the two control groups, however, is not statistically significant in this specification.

Table 3.7 Pre-Treatment Results: Specification #1

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Matching characteristics									
Employment growth rate, 1990-1980 (%)	0.45	0.1066	0.9155	-1.61	-0.4294	0.6695	2.06	0.4441	0.6588
Retail employment growth rate, 1990-1980 (%)	-3.05	-0.2940	0.7699	-0.16	-0.0191	0.9848	-2.89	-0.2805	0.7802
Population growth rate, 1990-1980 (%)	0.46	0.8230	0.4143	-0.70	-0.9633	0.3400	1.16	1.4350	0.1574
Fraction of retail employment, 1990	0.00	0.6848	0.4966	0.00	-0.2429	0.8090	0.01	0.7159	0.4773
Other characteristics									
Employment density, 1990 (jobs/sq.mi.)	-1485	-2.2444	0.0292	-572	-1.1557	0.2532	-912	-1.1880	0.2403
Population density, 1990 (persons/sq.mi.)	-599	-0.5627	0.5761	4459	6.9098	0.0000	-5058	-5.3095	0.0000
Fraction of Black population	0.00	-0.0514	0.9592	0.28	7.3246	0.0000	-0.28	-6.8041	0.0000
Fraction of Hispanic population	0.12	3.2738	0.0019	0.18	4.9900	0.0000	-0.06	-1.3875	0.1713
Median household income ($)	-1503	-0.8420	0.4037	-11989	-7.4885	0.0000	10486	5.8513	0.0000
Per capita income ($)	-3067	-3.6449	0.0006	-7803	-9.0969	0.0000	4735	4.8458	0.0000
Fraction of college graduate	-0.03	-4.1118	0.0001	-0.07	-10.1965	0.0000	0.04	3.7822	0.0004
Fraction of persons lacking High school diploma	-0.01	-0.8677	0.3896	0.06	6.0031	0.0000	-0.08	-5.8637	0.0000
Median value of property ($)	-38598	-3.4347	0.0012	-98300	-8.0461	0.0000	59702	4.1315	0.0001
Median rent ($)	-41.50	-1.6723	0.1006	-156.65	-6.1747	0.0000	115.15	5.0385	0.0000
Number of observations	52			52			52		
One-group Hotelling T2	2.6044			3.6930			1.6833		
F(4, 48)	0.8371			1.1871			0.5411		
Prob > F(4, 48)	0.4794			0.3233			0.6562		

Table 3.8 Post-Treatment Results: Specification #1

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Employment growth rate, 1997-1990 (%)	**177.18**	**3.1038**	**0.0031**	-18.21	-0.1571	0.8758	**195.39**	**2.0457**	**0.0460**
Retail employment growth rate, 1997-1990 (%)	**201.74**	**2.6736**	**0.0101**	83.76	0.8289	0.4110	*117.98*	*1.9417*	*0.0577*
Population growth rate, 1997-1990 (%)	4.46	1.4925	0.1417	*5.74*	*1.9177*	*0.0608*	-1.28	-0.6083	0.5457

Table 3.9 Pre-Treatment Results: Specification #5

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Matching characteristics									
Employment growth rate, 1990-1980 (%)	-3.29	-0.8124	0.4201	-5.29	-1.3901	0.1701	1.99	0.3674	0.7147
Retail employment growth rate, 1990-1980 (%)	0.06	0.0059	0.9953	-9.66	-1.2304	0.2238	9.72	0.8674	0.3895
Population growth rate, 1990-1980 (%)	-0.20	-0.2220	0.8252	-0.50	-0.4199	0.6762	0.31	0.2601	0.7958
Fraction of retail employment, 1990	0.00	0.6842	0.4967	0.00	-0.5369	0.5935	0.01	0.8798	0.3828
Employment density, 1990 (jobs/sq.mi.)	-224.90	-0.9330	0.3549	143.07	1.2426	0.2193	-367.97	-1.4732	0.1464
Other characteristics									
Population density, 1990 (persons/sq.mi.)	-428	-0.4269	0.6711	4352	6.6257	0.0000	-4781	-6.0960	0.0000
Fraction of Black population	0.00	-0.0021	0.9984	0.31	7.6773	0.0000	-0.31	-7.4197	0.0000
Fraction of Hispanic population	0.13	4.1078	0.0001	0.14	4.1767	0.0001	0.00	-0.1223	0.9031
Median household income ($)	-3100	-1.7692	0.0824	-12725	-6.9473	0.0000	9624	4.8076	0.0000
Per capita income ($)	-3854	-4.1039	0.0001	-7755	-7.2167	0.0000	3901	3.2183	0.0022
Fraction of college graduate	-0.04	-5.1509	0.0000	-0.06	-8.4069	0.0000	0.03	3.1418	0.0027
Fraction of persons lacking High school diploma	-0.01	-0.5455	0.5876	0.07	6.2125	0.0000	-0.08	-5.9810	0.0000
Median value of property ($)	-45630	-3.9443	0.0002	-95309	-7.7692	0.0000	49679	3.1852	0.0024
Median rent ($)	-60.45	-2.7381	0.0083	-168.34	-6.3545	0.0000	107.89	4.1993	0.0001
Number of observations	56			56			56		
One-group Hotelling T2	3.6659			4.9991			4.229		
F(5, 51)	0.6799			0.9271			0.7843		
Prob > F(5, 51)	0.6407			0.4712			0.5658		

Table 3.10 Post-Treatment Results: Specification #5

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Employment growth rate, 1997-1990 (%)	**128.90**	**2.3285**	**0.0236**	-22.12	-0.2085	0.8356	*151.02*	*1.6994*	*0.0949*
Retail employment growth rate, 1997-1990 (%)	*128.32*	*1.8646*	*0.0676*	88.43	1.0199	0.3122	39.89	0.5917	0.5565
Population growth rate, 1997-1990 (%)	4.00	1.3536	0.1814	*5.22*	*1.6794*	*0.0987*	-1.22	-0.6187	0.5387

Table 3.11 Pre-Treatment Results: Specification #9

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Matching characteristics									
Employment growth rate, 1990-1980 (%)	2.68	0.4697	0.6408	0.01	0.0022	0.9982	2.67	0.4732	0.6384
Retail employment growth rate, 1990-1980 (%)	0.65	0.0426	0.9662	3.80	0.3079	0.7596	-3.16	-0.2130	0.8323
Population growth rate, 1990-1980 (%)	-0.47	-0.5090	0.6132	-0.75	-0.4613	0.6468	0.27	0.1765	0.8607
Fraction of retail employment, 1990	0.01	0.6218	0.5372	0.00	-0.5586	0.5792	0.01	0.9111	0.3671
Employment density, 1990 (jobs/sq.mi.)	-422.69	-1.4359	0.1580	99.92	0.6350	0.5286	-522.61	-1.6346	0.1091
Fraction of Hispanic population	0	0.6254	0.5349	0	1.5027	0.1399	0	-0.3377	0.7371
Other characteristics									
Population density, 1990 (persons/sq.mi.)	-276.90	-0.2756	0.7842	4350.17	5.0964	0.0000	-4627.07	-4.9893	0.0000
Fraction of Black population	0.07	1.1962	0.2379	0.32	7.3223	0.0000	-0.26	-6.3247	0.0000
Median household income ($)	-1105	-0.6842	0.4974	-9248	-5.5088	0.0000	8144	4.7223	0.0000
Per capita income ($)	-1829	-2.7914	0.0077	-4554	-7.0258	0.0000	2725	4.3784	0.0001
Fraction of college graduate	-0.02	-3.0454	0.0039	-0.04	-6.5148	0.0000	0.02	3.5606	0.0009
Fraction of persons lacking High school diploma	-0.01	-1.5611	0.1255	0.08	7.3616	0.0000	-0.09	-8.7700	0.0000
Median value of property ($)	-22846	-2.2882	0.0269	-63517	-6.2412	0.0000	40672	4.3321	0.0001
Median rent ($)	-31.61	-1.2707	0.2104	-145.04	-5.7351	0.0000	113.43	4.3737	0.0001
Number of observations	46			46			46		
One-group Hotelling T2	3.9373			3.9614			3.8512		
F(6, 40)	0.5833			0.5869			0.5706		
Prob > F(6, 40)	0.7414			0.7387			0.7512		

Table 3.12 Post-Treatment Results: Specification #9

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Employment growth rate, 1997-1990 (%)	**186.38**	**3.0049**	**0.0043**	71.91	0.7790	0.4400	*114.47*	*1.7115*	*0.0939*
Retail employment growth rate, 1997-1990 (%)	*151.47*	*1.8608*	*0.0693*	81.69	0.8586	0.3951	69.79	1.0468	0.3008
Population growth rate, 1997-1990 (%)	3.22	0.9476	0.3484	1.73	0.5507	0.5845	1.48	0.6200	0.5384

Table 3.13 Pre-Treatment Results: Specification #10

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Matching characteristics									
Employment growth rate, 1990-1980 (%)	-4.89	-1.1183	0.2699	-6.25	-1.1707	0.2485	1.35	0.2446	0.8080
Retail employment growth rate, 1990-1980 (%)	8.65	0.6672	0.5084	14.76	1.2869	0.2054	-6.11	-0.3424	0.7338
Population growth rate, 1990-1980 (%)	-0.74	-0.6752	0.5033	1.66	1.2016	0.2364	-2.40	-1.6834	0.0999
Fraction of retail employment, 1990	-0.01	-1.1514	0.2562	0.00	-0.1485	0.8827	-0.01	-0.7500	0.4576
Employment density, 1990 (jobs/sq.mi.)	-157.30	-0.6117	0.5441	39.51	0.2296	0.8196	-196.81	-0.6206	0.5383
Fraction of persons lacking High school diploma	0	0.1005	0.9204	0	1.6657	0.1034	0	-1.0378	0.3054
Other characteristics									
Population density, 1990 (persons/sq.mi.)	82.57	0.0782	0.9380	4726.85	5.2841	0.0000	-4644.28	-4.2375	0.0001
Fraction of Black population	0.12	1.8701	0.0686	0.32	6.7763	0.0000	-0.20	-5.0157	0.0000
Fraction of Hispanic population	0	2.1015	0.0418	0	6.1577	0.0000	0	-3.0818	0.0037
Median household income ($)	-5392	-2.6706	0.0108	-12785	-6.6846	0.0000	7393	3.2173	0.0025
Per capita income ($)	-4854.50	-3.8698	0.0004	-8309.02	-10.2253	0.0000	3454.52	2.4240	0.0198
Fraction of college graduate	-0.04	-4.0164	0.0002	-0.07	-9.6531	0.0000	0.03	3.0228	0.0043
Median value of property ($)	-59814	-4.3369	0.0001	-86060	-8.4307	0.0000	26245	1.6930	0.0980
Median rent ($)	-83.48	-3.3417	0.0018	-176.40	-7.1220	0.0000	92.93	3.2669	0.0022
Number of observations	42			42			42		
One-group Hotelling T2	6.4694			12.0528			7.4849		
F(6, 36)	0.9467			1.7638			1.0953		
Prob > F(6, 36)	0.4744			0.1345			0.384		

Table 3.14 Post-Treatment Results: Specification #10

Tract characteristics	Treated-Control I			Treated-Control II			Control II-Control I		
	Mean	t-stat.	p-value	Mean	t-stat.	p-value	Mean	t-stat.	p-value
Employment growth rate, 1997-1990 (%)	**214.66**	**3.5554**	**0.0010**	**151.78**	**2.4136**	**0.0203**	**62.88**	**2.9706**	**0.0050**
Retail employment growth rate, 1997-1990 (%)	**225.64**	**2.8993**	**0.0060**	**184.89**	**2.1044**	**0.0415**	40.75	1.0128	0.3171
Population growth rate, 1997-1990 (%)	*4.99*	*1.9665*	*0.0560*	2.43	0.9112	0.3675	2.56	0.9925	0.3268

3.5.4 Discussion

The analysis of census tract employment above revealed growth patterns that can be interpreted as an evidence for negative spillovers. Under the assumption that growth patterns should be maintained *ceteris paribus*, employment growth rates in the two control groups, neither of which are in close proximity to the new highway, should be similar before and after the highway is open. However, the presence of the new highway not only altered employment growth pattern in treated tracts that are close to the highway – employment and retail employment in these tracts outgrew those in their controls by 100% to 200% in most matching characteristics – it also created dissimilarities in growth patterns between the two control groups.

Table 3.15 Summary of Mean Differences in Employment Growth Rates

	Employment	**Specification**				
Pre-Treatment (1990-1980)	**Growth rates**	**Basic**	**1**	**5**	**9**	**10**
Treated-Control I	Mean Difference	-1.94	0.45	-3.29	2.68	-4.89
	t-statistic	-0.5519	0.1066	-0.8124	0.4697	-1.1183
Treated-Control II	Mean Difference	-2.57	-1.61	-5.29	0.01	-6.25
	t-statistic	-1.0024	-0.4294	-1.3901	0.0022	-1.1707
Control II-Control I	Mean Difference	0.63	2.06	1.99	2.67	1.35
	t-statistic	0.1437	0.4441	0.3674	0.4732	0.2446
Post-Treatment (1997-1990)						
Treated-Control I	Mean Difference	195.58	177.18	128.90	186.38	214.66
	t-statistic	3.2548	3.1038	2.3285	3.0049	3.5554
Treated-Control II	Mean Difference	35.88	-18.21	-22.12	71.91	151.78
	t-statistic	0.3627	-0.1571	-0.2085	0.779	2.4136
Control II-Control I	Mean Difference	159.71	195.39	151.02	114.47	62.88
	t-statistic	2.3763	2.0457	1.6994	1.7115	2.9706

As shown in Table 3.15, tract employment growth rates in the first control group generally lagged far behind those in the other census tract groups. Employment growth rates in the second control group, albeit faster than in the first control group, in a majority of cases, also fell behind those in the treated group, but the gap is much smaller, and statistically insignificant. Assuming that employment growth rates in the second control group followed the general trend of regional economy, uninterrupted by shock from the new highway, the relatively sluggish growths in the first control group provide evidence of negative spillover of highway within a metropolitan economy. The results in Table 3.16 also suggest the same pattern of growth for retail employment although the extent of spillovers appears to be less severe even though the evidence is not as clear-cut as in the case of total employment growth.

Table 3.16 Summary of Mean Differences in Retail Employment Growth Rates

	Retail Employment	**Specification**				
Pre-Treatment (1990-1980)	**Growth rates**	**Basic**	**1**	**5**	**9**	**10**
Treated-Control I	Mean Difference	6.77	-3.05	0.06	0.65	8.65
	t-statistic	1.2204	-0.2940	0.0059	0.0426	0.6672
Treated-Control II	Mean Difference	1.44	-0.16	-9.66	3.80	14.76
	t-statistic	0.2368	-0.0191	-1.2304	0.3079	1.2869
Control II-Control I	Mean Difference	5.32	-2.89	9.72	-3.16	-6.11
	t-statistic	0.9299	-0.2805	0.8674	-0.2130	-0.3424
Post-Treatment (1997-1990)						
Treated-Control I	Mean Difference	199.06	201.74	128.32	151.47	225.64
	t-statistic	2.9536	2.6736	1.8646	1.8608	2.8993
Treated-Control II	Mean Difference	69.37	83.76	88.43	81.69	184.89
	t-statistic	0.7694	0.8289	1.0199	0.8586	2.1044
Control II-Control I	Mean Difference	129.69	117.98	39.89	69.79	40.75
	t-statistic	2.0839	1.9417	0.5917	1.0468	1.0128

Table 3.17 shows the summary of results for population growth rates. The growth rate difference between groups range from –64% to 5.74%. In most cases, the differences are small and not statistically significant. The empirical results imply that while new highways can cause considerable shifts in employment growth patterns in a metropolitan area, they may not have as much influence on residential location as other factors, such as crime rates, school quality, etc.

Table 3.17 Summary of Mean Differences in Population Growth Rates

Pre-Treatment (1990-1980)	Population Growth rates	Specification: Basic	1	5	9	10
Treated-Control I	Mean Difference	-0.09	0.46	-0.20	-0.47	-0.74
	t-statistic	-0.1220	0.8230	-0.2220	-0.5090	-0.6752
Treated-Control II	Mean Difference	-0.93	-0.70	-0.50	-0.75	1.66
	t-statistic	-1.3731	-0.9633	-0.4199	-0.4613	1.2016
Control II-Control I	Mean Difference	0.84	1.16	0.31	0.27	-2.40
	t-statistic	0.8816	1.4350	0.2601	0.1765	-1.6834
Post-Treatment (1997-1990)						
Treated-Control I	Mean Difference	-59.77	4.46	4.00	3.22	4.99
	t-statistic	-0.9205	1.4925	1.3536	0.9476	1.9665
Treated-Control II	Mean Difference	4.06	5.74	5.22	1.73	2.43
	t-statistic	1.4263	1.9177	1.6794	0.5507	0.9112
Control II-Control I	Mean Difference	-63.83	-1.28	-1.22	1.48	2.56
	t-statistic	-0.9756	-0.6083	-0.6187	0.62	0.9925

The test of robustness is admittedly limited, due to the difficulties in census tract matching. However, the results from five different matching specifications appear to follow the same pattern, thus providing some assurance that the outcomes did not occurred by accident in the census tract matching process. The problems regarding census tract matching remain important, and may be improved by using a larger set of potential controls, i.e., including tracts from other counties within the metropolitan area. This solution may not guarantee better matching quality, nonetheless, as other spatial characteristics of distant census tracts can also be significantly different from treated tracts.

3.6 Conclusion and Policy Implications

The quasi-experimental study in this chapter compares employment impacts of the Interstate 105 (Century Freeway) in three groups of census tracts in Los Angeles County to uncover evidence of spillovers of new highways at a metropolitan level. The three groups include the treated group, first control group, and second control group, which are defined according to their relative distances to the freeway, the treated group being the nearest and the second control group the farthest. Census tracts in each control group are chosen such that they are most similar to those in the treated group, using a statistical matching method that involves the ranking of Mahalanobis distances. The census tract matching procedures yield three groups of census tracts with similar patterns of employment growths and other characteristics, based on the data between 1980 and 1990, the decade prior to the opening of the Century Freeway.

While the employment growth patterns in the three groups are similar in the 1980's, they became very different in the 1990's. On average, employment growth rates in the treated groups increased substantially from the previous decade, most likely as a result of the new freeway, which was opened in 1993. Employment growth rates in both control groups did not rise nearly as fast. Particularly, the employment growth rates in first control group, which is closer to the freeway of the two control groups, are much lower than those in the treated group, and the mean difference of the growth rates between the two groups is statistically significant. The employment growth rates in the second control group, while in some cases lagging behind the treated group, are higher than are those in first control group, despite being farther away from the highway. The patterns of employment growths in the three groups of census tracts are quite robust, regardless of specifications used in the matching procedures.

The growth patterns of census tract employment in the quasi-experimental study shows that being closer to a new highway does not necessarily imply benefiting from it, but may imply losses instead, the basic notion of negative spillovers. The patterns of employment growth rates in the three groups of census tracts suggest that while tracts along the highway clearly benefit from rapid employment growth after the highway was opened, tracts that are in the vicinity of, but not next to the highway, may suffer slower employment growth. The fact that tracts that are very far from the highway, hence less likely to gain or lose from its opening, grew faster than those that are close but not next to the highway, corroborates the negative spillovers hypothesis. These empirical results provide a new piece of evidence that a new highway can exert negative economic spillovers in highly urbanized areas, as indicated in this case of metro Los Angeles. A new highway may induce rapid employment gain in a narrow corridor of approximately two miles, but it may slow employment growth in nearby locations outside this corridor. The negative employment impacts, however, are not likely to extend beyond 10 miles of the highway centerline.

This empirical study has some critical policy implications on highway finance. It demonstrates that even when the financial responsibility mismatch is a concern, the highway finance reform that calls for decentralizing highway investment decision may not be appropriate at the metropolitan level. Since benefits of new highway investment in urbanized areas are confined within a narrow corridor, which likely spans several cities within a metro area, decentralizing highway finance responsibility to local jurisdictions will reduce cross subsidies among cities, but not within. Therefore, the decentralization will not solve the mismatch problem entirely. A better solution might be to incorporate a more thorough analysis of economic impacts, focusing on welfare distribution within neighborhoods surrounding the new highway in the project evaluation procedure. In this way, properties that will likely gain from the highway can be identified, and property taxes can be levied on owners of these properties. To mitigate the problem of financial responsibility mismatch in highway finance, these tax revenues, along with highway user fees, can be used to finance the construction of the new highway, as well as to compensate for those who lose because of the negative spillovers.

References

Boarnet, Marlon G. 1998. "Spillovers and the Locational Effects of Public Infrastructure," *Journal of Regional Science*, 38, 381-400.

Boarnet, Marlon G. and Haughwout, Andrew F. 2000. "How Highways Influence Metropolitan Development: Evidence and Policy Implications" A Discussion Paper Prepared for the Brooking Institution's Center on Urban and Metropolitan Policy, Washington, D.C.

Chandra, Amitabh and Thompson, Eric. 2000. "Does Public Infrastructure Affect Economic Activity? Evidence from the Rural Interstate Highway System," *Regional Science and Urban Economics*, 30, 457-490.

Fernald, John G. 1999. "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity," *American Economic Review*, 89, 619-638.

Garcia-Mila, Teresa, McGuire, Therese J. and Porter, Robert H. 1996. "The Effect of Public Capital in State-level Production Functions Reconsidered," *The Review of Economics and Statistics*, 78, 177-180.

Holtz-Eakin, Douglas. 1994. "Public Sector Capital and the Productivity Puzzle," The Review of Economics and Statistics, 76, 12-21.

Holtz-Eakin, Douglas and Schwartz, Amy E. 1995. "Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways," *International Tax and Public Finance*, 2, 459-468.

Kelejian, Harry H. and Dennis P. Robinson. 1994. "Infrastructure Productivity: A Razor's Edge," Working Paper No. 94-3. College Park, MD: University of Maryland Department of Economics

Rephann, Terance and Isserman, Andrew. 1994. "New Highways as Economic Development Tools: An Evaluation Using Quasi-Experimental Matching Methods," *Regional Science and Urban Economics*, 24, 723-751.

Rosenbaum, Paul R. 1989. "Optimal Matching for Observational Studies," *Journal of American Statistical Association*, 84, 1024-1032.

CHAPTER 4

Conclusion

While few would dispute the tremendous economic growth impact of the bulk of the highway network which provides universal connection within a country[1], there is much evidence that an incremental investment in highways, added to a fully developed highway network, has relatively little impact on overall economic growth. Many researchers argue that although new highways no longer induce overall growth, they play a different but critical role in channeling development between places (Forkenbrock and Forster, 1990; Cervero and Landis, 1995). Jobs that follow commercial and residential development to a new highway corridor, for instance, might have been located somewhere else had that new highway not been built. If new highways actually cause relocations of economic activities from one place to another, such redistributions reflect economic losses outside of the highway corridor, and should factor into the evaluation process of new highway projects. Boarnet (1998), referring to these losses as *negative economic spillovers*, suggested that a careful analysis of highway economic benefits – or losses - both inside and outside the highway impact area is necessary to ensure efficient and equitable investments of highways.

Unfortunately, the current practice of project evaluation relies heavily on efficiency criteria, such as cost-benefit ratio, and virtually ignores distribution issues because of analytical difficulties. The analysis of economic impacts is also difficult, and the distribution of economic impacts even more so. Small (1999) suggested that due to such difficulties, applying the cost-benefit analysis to all projects unselectively might result in a balanced distribution of welfare, thus indirectly solving the problem. However, this approach may not apply in the case of economic spillovers, due to spatial distribution of economic impacts over small and highly localized areas. Therefore, the main objective of this dissertation is to contribute to the understanding of the economic impact of new highways by building on previous studies on the economic spillovers of highway investments (e.g. Forkenbrock and Forster, 1990; Rephann and Isserman, 1994; and Boarnet, 1998).

In addition to the concern over the implications of negative spillovers on highway project evaluations, some researchers have used the evidence of negative spillovers of highways to argue for a change in the way new highways are financed (Boarnet and Haughwout, 2000). Because new highways no longer generate benefits over a wide geographic area, at the national level, these researchers reasoned, it makes no sense to continue to finance them by federal funds, as in the case of most highway projects in the United States. Local jurisdictions, which gain an economic benefit from a new highway, should contribute more proportionately to the costs of building it, and the localities that are harmed by the flight of mobile factors should not have to pay for the highway actually causing their losses. Boarnet (1998) argued that a reform of finance policy that would decentralize highway finance decisions to a more local level can mitigate the problem of financial responsibility mismatch.[2]

A call for such an overhaul in highway finance policy requires thorough investigations of the problem to answer many questions that can be raised, e.g. how

---

[1] E.g., the National System of Interstate and Defense Highways in the United States.
[2] The call for decentralization of highway finance has begun to translate into highway finance policies. For example, the Transportation Equity Act of the 21st Century (TEA-21) includes provisions that require state governments to pay into highway funds.

effective is the reform policy in solving the financial responsibility mismatch problem, to what extent should highway finance be decentralized, and what are other potential impacts. As can be seen in the review of the literature in Chapter 1, the current literature on economic spillovers of highway investment cannot fully inform these policy questions. Economic spillovers have not been examined at any level of detail lower than counties, and hence, nothing can be said about highway finance policy at the level of metropolitan areas. Moreover, the political economy of decentralization policies is not well understood. For example, it is unclear how local governments will respond to the decentralization policy as far as their highway investment behaviors. This dissertation illuminates these issues by refining empirical evidence of spillovers in a metropolitan area and improving a theoretical model of government decisions to build highways under various schemes of finance policy.

The political economy of the highway finance decentralization is examined in Chapter 2. The behaviors of local governments' highway investments are modeled and simulated, with the modeling techniques borrowed from the inter-jurisdictional tax competition literature. This is a major improvement over the past studies because highway investment decision-making processes and strategic behaviors of responsible governments under the decentralized policy are explicitly analyzed for the first time. Under the assumption that policymakers try to maximize employment and output, the model simulations show that, due to negative spillovers, local governments, acting independently, will have incentives to overbuild highways in order to attract employment from their neighbors or to keep them from moving away. The Nash equilibrium investment and employment allocation under the decentralized finance policy are suboptimal compared to those under the centralized policy – the optimal investment level, which maximizes aggregate output, is significantly lower than the Nash investment. This result implies that even though decentralizing highway finance may solve the mismatch problem that is due to negative spillovers, another problem may arise: decentralized governments may invest too much in highways.

In Chapter 3, negative spillovers of highway investment in metropolitan areas are examined in a quasi-experiment study of the Interstate 105 in Los Angeles County. The much-improved geographic details of this study provides the missing piece of evidence of negative spillovers. The treatment in this quasi-experiment is the proximity to Interstate 105 (Los Angeles' Century Freeway), which opened in 1993. Employment and population growth in three groups of census tracts are observed over the 17-year period: the first ten years, prior to the treatment and the last seven years after the treatment. The first group of census tracts, the treated group, received the treatment –they are within a one-mile corridor of the Century Freeway. The other two groups of census tracts are control groups, from which census tracts are selected in such a way that they are of similar characteristics to those in the treated group. In order to capture the spatially varied economic impact of the highway, the two control groups are defined as follows: census tracts in the first control group are between two and ten miles of the highway, and those in the second group beyond ten miles. By design, growth patterns in all three groups are similar in the period before the treatment. If the highway exerts no negative spillovers, then the growth patterns in the three groups should not change significantly after the treatment.

The key finding of this empirical study is that, after the opening of the highway, the employment growth patterns in the three groups of census tracts did change substantially. The treated group of census tracts grew at the fastest rate while the first control group, the one that is near but not adjacent to the highway, at the slowest rate. The second control group, the one that is farthest from the highway, grew at a rate between the treated and the first control groups. The results are consistent with the hypothesis that the employment growth impact of the new highway is highly localized, in this case within the one-mile corridor of the highway. Moreover, with such patterns of growth, it is not unreasonable to infer that the employment growth surge within the one-mile highway corridor may be drawn from nearby areas, i.e. those corresponding to the first control group, but to the lesser extent from areas that are very distant from the highway, i.e. those corresponding to the second control group. This piece of evidence supports the hypothesis that negative spillovers exist even at a very small geographic level within metropolitan areas.

The pieces of evidence about negative spillovers are now ready to be put together. The empirical evidence from this dissertation and past studies confirms that economic spillovers vary with geographic scale. While there seems to be no evidence of spillovers at the state level, negative spillovers are significant at the county level as well as at the census tract level within metropolitan areas. Spillovers are contained within large geographic areas, like states, but not cities and counties, probably due to the relative ease in factor mobility among such small geographic areas. In addition, the evidence shows that the geographic area of loss may be large, despite a very small benefiting area.[3] The

[3] The narrow benefiting corridors seem to draw from a large area (evidence from county-level negative spillover studies), while the losses seem to decrease with distance (evidence from this dissertation).

empirical findings of this dissertation confirm the highly localized nature of highway benefits, which verifies the concern of highway funding responsibility mismatch. However, these results must be interpreted with care before they can be used to inform the highway finance policy.

The evidence of negative spillovers of highways may not justify the solution to the mismatch problem by decentralizing funding responsibility for two reasons. First, the very small benefiting geographic areas, a long narrow corridor, are often bound to traverse many jurisdictions. The decentralization may reduce the mismatch among jurisdictions, but not within each of them. Thus, measures must still be taken to ensure that the benefiting area within one jurisdiction pays a fair share for the highway. Second, taken with the results from the theoretical model discussed earlier, it is the presence of negative spillovers that can cause further problems if the highway finance is decentralized. The inter-jurisdictional competition to build highways to attract economic activities – a valuable tax base, are possible, and too much investment in highways may result. For these reasons, the policy recommendation for highway finance decentralization is not likely to work well at the metropolitan level.

Overall, this dissertation's policy recommendation regarding the highway finance policy in metropolitan areas is along the same lines as those of Boarnet and Haughwout. Regional governments, such as MPOs, are the best governing bodies for highway investment decisions because it is not the presence of negative spillovers per se, but rather the attempt to match benefiting geographic area with highway finance responsibility that necessitates the decentralization of highway finance. While there is little doubt that at this point in time in the United States federal government should consider passing on its role in highway investment decision to states, some degrees of centralization of highway investment decision must be maintained within states and more importantly within metropolitan areas.

The policy recommendations in this dissertation, although more refined than those in the past, are still far from definite. Further research must be done in order to confirm the degree of localization of highway benefits. The same method of empirical research can be applied to data from other metropolitan areas within the United States. If the data are more extensive, e.g., more data on employment by industrial sectors, a larger number of census tracts that can be used for controls, etc., the results will likely be more precise. Other methods for examining spillovers are also available, such as the simultaneous population and employment intrametropolitan growth models (Boarnet, Chalermpong, and Geho, 2002), and can be applied to the data used in this dissertation to verify the results. As far as the political economy of the decentralized highway finance policy, the only avenue to explore the problem remains the theoretical modeling, due to the lack of decentralized system of highway finance that can be investigated empirically. The theoretical model, however, can be refined to be more realistic. As a first step, for example, the model may be extended to consider other types of objective functions of the local governments. The consumption sector, in addition to the production sector, may also me modeled, and more realistic highway cost functions may be used. The results from the improvement to both sides of the research will surely provide more refined policy prescriptions for the appropriate role of federal, state and local highway finance, and will inform an important part of the looming debate that will occur during the renewal of Transportation Equity Act of the 21st Century, which expires in 2005.

References

Boarnet, Marlon G. 1998. "Spillovers and the Locational Effects of Public Infrastructure," *Journal of Regional Science*, 38, 381-400.

Boarnet, Marlon G., Chalermpong, Saksith, and Geho, Elizabeth. 2002. "Specification Issues in Models of Population and Employment Growth," Submitted to *Papers in Regional Science.*

Chandra, Amitabh and Thompson, Eric. 2000. "Does Public Infrastructure Affect Economic Activity? Evidence from the Rural Interstate Highway System," *Regional Science and Urban Economics*, 30, 457-490.

Boarnet, Marlon G. and Haughwout, Andrew F. 2000. "Do Highways Matter? Evidence and Policy Implications of Highways' Influence Metropolitan Development" A Discussion Paper Prepared for the Brooking Institution's Center on Urban and Metropolitan Policy, Washington, D.C.

Cervero, Robert and Landis, John. 1995. "The Transportation-Land Use Connection Still Matters," *Access*, Fall 1995, 2-10.

Forkenbrock, David J. and Foster, Norman J. 1990. "Economic Benefits of a Corridor Highway Investment," *Transportation Research Part A*, 24, 303-312. .

Rephann, Terance and Isserman, Andrew. 1994. "New Highways as Economic Development Tools: An Evaluation Using Quasi-Experimental Matching Methods," *Regional Science and Urban Economics*, 24, 723-751.

Small, Kenneth A. 1999. "Project Evaluation," In *Essays in Transportation Economics and Policy*, J. Gomez-Ibanez, W. B. Tye, and C. Winston, eds. Washington: Brookings Institution Press.

APPPENDIX A

GIS Data Preparation

A.1 GIS Data

The following GIS-ArcView shape files were used for spatial analysis.

`Catrct.shp`

This shape file, a polygon theme, contains all California census tracts by the Bureau of Census's 1990 definition. The table associated with this shape file provides the 1990 population and housing census data, as well as the estimates of 1997 population. This GIS file was obtained from ESRI Data & Map CD-ROM Number 3 (Western United States), owned by the Institute of Transportation Studies.

`Cards.shp`

This shape file, a polyline theme, contains all major roads in California, including Interstate Highways, US Routes, State Routes, as well as arterial roads. It was also obtained from the above source.

A.2 GIS Procedures for Selecting Treated Census Tracts

To minimize computation time, the California census tracts and major roads shape files were converted to smaller shape files that cover only the areas of interest. (This was done by running query to choose only census tracts with `Cnty_fips` codes equal 037 for Los Angeles County, 059 for Orange County, and so on.) For instance, `Lacnty.shp` and `Lacntyrds.shp` contain all of Los Angeles County's census tracts and major roads, respectively. Similar files were created for Orange, Riverside, San Bernardino and Ventura counties. Additionally, a shape file called `i105.shp` that contains all segments of the Century Freeway was created from the major roads shape file. After these GIS maps are ready, the following GIS procedure is used to select treated tracts for the quasi-experiment of the Century freeway.

Step I: Census tract shape files, such as `Lacnty.shp`, which are a polygon theme, were converted to a point theme that contains centroids of all census tracts, and saved as `Lacntypt.shp`. This allows us to run a Geoprocessing procedure called spatial join, which computes the shortest distance between each point in a point theme to each line segment in a polyline theme. Spatial joining the `i105.shp` polyline theme to the `Lacntypt.shp` point theme yielded the distance between each census tract (centroid) to the Century Freeway.

Step II: To choose treated tracts, a query was run to select tracts with the distance obtained in *Step I* that is **shorter than one mile**. This selection criterion is based on the hypothesis that the positive employment impact from a highway is strongest within one mile from its centerline. To test another hypothesis, we can specify the selection criteria differently. For example, to isolate the negative effects of noise and air pollution from the highway, the selection criteria could be to choose tracts with the freeway distance greater than one quarter of a mile but shorter than one mile.

Step III: The previous two steps yielded 73 tracts that fall into "treated" category specified by the one-mile corridor selection criterion. Among these, there were eleven cases where census tract definitions changed between 1980 and 1990. In two cases, the 1990 tract definition is a result of merging two or more 1980 tracts. It is hence a simple matter to convert the 1980 data to 1990 tract definition, as described in the previous section. In nine other cases, however, the changes involved tract splitting. For the reasons discussed earlier, these tracts were discarded and 64 tracts are used as final treated tracts.

(Note that the 1980 employment data for tract 2420 is missing, thus reducing the final number of treated tracts to 63.)

A.3 1980 and 1990 Comparability

In mature urban areas like South Central Los Angeles, there are relatively few significant changes in census tract definitions between 1980 and 1990. These changes usually involve merging two or more 1980 census tracts (e.g. tracts with declining population) into one 1990 census tract. In this quasi-experiment, the 1990 definition of census tracts is used as the unit of observation. Therefore, the employment and population data in the cases of merging can be adjusted straightforwardly. For example, if 1980 tracts 10.01 and 10.02 were merged into a 1990 tract 10, then the population of tract 10 in 1980 is equal to the sum of 1980 population in both tract 10.01 and 10.02.

However, in fast growing areas, such as the southern part of Orange County and urbanized areas in Riverside and San Bernardino counties, many significant changes in census tract definition occurred between 1980 and 1990. A large number of changes involve splitting very large 1980 tracts into two or more smaller tracts in 1990. It is difficult to make adjustment to the population and employment data in the case of tract splitting for two reasons. First, since the 1980 definition of census tract is a coarser unit of observation than the 1990 definition, the information contained in the 1980 census is less detailed than its equivalent in the 1990 census. Second, the Bureau of Census does not provide the exact description of the split, thus precluding any reliable estimate of the data in subsequent years. One way to estimate the 1980 data for 1990 census tracts is to use land area, which is available in the ESRI map, as weight. However, since employment tends to cluster, and not to spread evenly, this method of estimation is highly unreliable.

The problem in dealing with splitting tract can be solved in two ways. First, we can use 1980 tract definitions as the unit of observation. This would eliminate the problem mentioned above, but raise another. Since the census tract map of 1980 definition is not available in electronic format, a substantial amount of modification of the currently available 1990 census tract map is needed for the GIS analysis required to do census tract matching. However, since the Orange County toll road is located in the southern part of the county, where most tracts are split tracts, the treated tracts, albeit split, cannot be discarded. Hence, the 1980 census tract definition is used as a unit of observation in the case of Orange County toll road.

The other solution is to drop split tracts. This is more appropriate when few tracts in the area of interest are split tracts. In the case of the Century Freeway (I-105), for example, the neighborhoods within 10 miles of the highway corridor are relatively mature and few changes in census tract definition – particularly splitting – occurred between 1980 and 1990 (eight percent of all 1990 tracts). Hence, a small fraction of treated tracts and potential control candidates are split tracts and can be discarded without significant impact on the result of the analysis. Moreover, the fact that most treated tracts are not split tracts provides further justification for not using split tracts as control candidates. Tract splitting is a sign of rapid urban development, which is not likely present in the mature urban area that is of interest in this part of the research.

APPENDIX B

Census Tract Matching Data Preparation

B.1 Creating a list of treated and control tracts

The results of GIS map preparation include two lists of census tracts – one for treated tracts and the other for controls. For the reason discussed above, 1990 tracts that result from 1980 split tracts are dropped. 1990 tracts that result from merged 1980 tracts were also identified since they are necessary for updating the 1980 employment spreadsheet. The updating procedure is simple. First, 1980 tracts that were merged to form a 1990 tracts were identified. Then, the rows corresponding to these tracts were summed in a new row for the 1980 data for the 1990 tract definition. Finally, the rows corresponding to the original 1980 merged tracts were deleted.

B.2 Gleaning data for census tracts of interest by filter

The employment and census data spreadsheet contains data for all census tracts in Los Angeles county. To obtain the data for tracts of interest, the updated lists of treated and control tracts from the previous section were used to filter the three spreadsheets, which were previously merged by census tract. The resulting two spreadsheet are called `i105treated.xls` and `i105ctrl.xls`. Each of these was sorted by census tract.

B.3 Constructing matching data

Employment and population growth rates were computed from the 1980 and 1990 data in both spreadsheet. Then, the spreadsheet for treated tracts was stacked over the one for control tracts, and then an additional column `tractid` was created, with an identification number for each tract. The result was exported as a text file called il05matchdata.txt. Figure B.1 shows the data structure that is used as input for computing the Mahalanobis distance in the next step.

Figure B.1 Data Structure of Input File

	tractid	tract90	char1	char2	char3	.....	charK
Treated Tracts	1	xxxx.xx	xxx	xxx	xxx	.....	xxx
	2	xxxx.xx	xxx	xxx	xxx	.....	xxx
	3	xxxx.xx	xxx	xxx	xxx	.....	xxx
	.	.	.	.	.	.....	.
	.	.	.	.	.	.....	.
	n-1	xxxx.xx	xxx	xxx	xxx	.....	xxx
	n	xxxx.xx	xxx	xxx	xxx	.....	xxx
Control Tracts	n+1	xxxx.xx	xxx	xxx	xxx	.....	xxx
	n+2	xxxx.xx	xxx	xxx	xxx	.....	xxx
	n+3	xxxx.xx	xxx	xxx	xxx	.....	xxx
	n+4	xxxx.xx	xxx	xxx	xxx	.....	xxx
	.	.	.	.	.	.....	.
	.	.	.	.	.	.....	.
	.	.	.	.	.	.....	.
	N-1	xxxx.xx	xxx	xxx	xxx	.....	xxx
	N	xxxx.xx	xxx	xxx	xxx	.....	xxx

Note:

1. Tracts with tractid 1 through n are treated tracts.
2. Tracts with tractid n+1 through N are control candidates.
3. There are n treated tracts, N-n control candidates, and N tracts overall.

APPENDIX C

STATA Codes for Census Tract Matching and Statistical Tests

C.1 Mahalanobis Distance Computation and Ranking

```
program define mdis

/* mdis computes Mahalanobis distance between treated tracts and tracts
in both control groups using characteristics 1 through k .
Note: The variance matrix V for M.D. calculation is computed from all
potential controls. */
/* mdis char_1 char_2 ... char_k outputname */
clear
quietly set mem 25m
set mat 800
local mp "C:\WINNT\Profiles\tan\Dissertation\empiric\I105\pre-post-
tests\\"
use `mp'i105matchingdata.dta, clear

/* Count number of arguments */
local k 1
while "``k''"~= "" {
 local k = `k' + 1
}
local k = `k' - 1
local out "``k''"
local outfile "`mp'\`out'"
local k =  k' - 1

/* Count number of treated tracts */
/* Note that for treated tracts, varlist group=0.
for control group I, group=1, and for control group II, group=2*/
quietly count if group==0
local N=r(N)

/* Loop for treated tract i */
local i=1
while `i'<=`N' {
 /* Create characteristics deviations from the treated tract */
 local j=1
 while `j' <= `k' {
  local temp = ``j'' in `i'
  g dev`j' = ``j'' - `temp'
  local j = `j' + 1
 }
 /* Save deviation variables in deviation matrix X */
 mkmat dev1 - dev`k' if group==1, matrix(X1)
 mkmat dev1 - dev`k' if group==2, matrix(X2)
 /* deviation variables are no longer needed */
 drop dev1 - dev`k'

 /* Compute the covariance matrix of matching characteristics*/
 local G=1 /* G is group index */
```

```
  while `G'<=2 {
   /* Compute deviations from mean */
   local j=1
   while `j' <= `k' {
    quietly summ ``j'' if group==`G'
    g d`j' = ``j'' - r(mean)
    local j = `j' + 1
   }
   local j=`j'-1
   mkmat d1 - d`j' if group==`G', matrix(V`G')
   quietly count if group==`G'
   /* compute covariance matrix */
   matrix V`G' = V`G''*V`G'/(r(N)-1)
   /* deviations are no longer needed. */
   drop d1 - d`j'
   mat D`G' = X`G'*inv(V`G')*X`G''
   local G=`G'+1
  }
mat MDIS = J(`N',1,9999)\(vecdiag(D1))'\(vecdiag(D2))'
/* Distance to tracts in ctrl groups */
mat MDIS[`i',1]=0 /* Distance to self (treated) */
mat drop D1 X1 V1 D2 X2 V2
svmat MDIS, name(mdis) /* save md into stata varlist from matrix */
rename mdis1 md`i'
mat drop MDIS
local i=`i'+1 /* to compute md for the next treated tract*/
}
local k=`k'+1

/* Ranking for each treated tract */
local n1s=`N'+1 /* index for the first ctrl I tract after all treated
tracts */
quietly count if group==1
local n1e=`n1s'+r(N)-1 /* index for the last ctrl I tract */
local n2s=`n1e'+1 /* index for the first ctrl II tract after all ctrl I
tracts */
quietly count if group==2
local n2e=`n2s'+r(N)-1 /* index for the last ctrl II tract */

g used=-1 /* used=1 if the tract is used as ctrl1, 2 for ctrl2 */
quietly replace used=0 in 1/`N' /* used=0 for treated tract */
g ctrl1=-1 /* tract90 of ctrl I for a given treated tract */
g ctrl2=-1 /* tract90 of ctrl II for a given treated tract */
g bad=0 /* bad match */
/* 1 for ctrl I with md>10; 2 for ctrl iI with md>10; 3 for both ctrl
md>10 */
g mdis1=999
g mdis2=999


local i=1
while `i'<=`N' {
 sort md`i' in `n1s'/`n1e'
 quietly replace used=1 in `n1s'
 local tr=tract90 in `n1s'
 quietly replace ctrl1=`tr' in `i'
 local tr=md`i' in `n1s'
```

```
   quietly replace mdis1=`tr' in `i'
   if md`i'>=10 in `n1s' {
    quietly replace bad=1 in `i'
    quietly replace bad=1 in `n1s'
   } /* bad=1 for ctrl1 with md>10 */
   sort md`i' in `n2s'/`n2e'
   quietly replace used=2 in `n2s'
   local tr=tract90 in `n2s'
   quietly replace ctrl2=`tr' in `i'
   local tr=md`i' in `n2s'
   quietly replace mdis2=`tr' in `i'
   if md`i'>=10 in `n2s' {
    if bad==1 in `i' {
     quietly replace bad=3 in `i'
    } /* bad=3 for both ctrl1 & ctrl2 with md>10 */
    if bad==0 in `i' {
     quietly replace bad=2 in `i'
    }
    quietly replace bad=2 in `n2s'
   }
  local i=`i'+1
 }
 sort tractid
 guniq
 keep tractid used-uniq2
 sort tractid
 save `outfile', replace

 end
```

C.2 Statistical Testing

```
prog define ttestdif
/* ttestdif char1 ... chark inputfile */
/* e.g.
ttestdif emp908 ret908 pop908 retfr9 empd9 popd9 pbl phi mdhhi pcap pba
pnob md_r med_v matchedx
or
ttestdif emp979 ret979 pop979 matched5
*/
clear
quietly set mem 25m
set mat 600
local mp "C:\WINNT\Profiles\tan\Dissertation\empiric\I105\pre-post-
tests\\"

use `mp'i105matchingdata

/* Count number of arguments */
local k 1
while "``k''"~= "" {
 local k = `k' + 1
}
local k = `k' - 1
local infile "`mp'\``k''"
```

```
mer tractid using `infile'
quietly count if _merge!=3
if r(N)>0 {
 display "Merging error"
}
else {
 quietly drop _merge
}
count if used==0
local n=r(N)
count if bad==3
local n=`n'-r(N)
drop if bad==3
mat T=J(`n',`k'-1,99999)
mat C1=J(`n',`k'-1,99999)
mat C2=J(`n',`k'-1,99999)
mat BAD=J(`n',1,0)
local i 1
local j 1
while `i'<=`n' {
 while `j'<=`k'-1 {
  local temp=``j'' in `i'
  if `temp'!=. {
   mat T[`i',`j']=`temp'
  }
  if `temp'==. {
   mat BAD[`i',1]=1
  }
 local j=`j'+1
 }
 local j=1
 local i=`i'+1
}
local i=1
while `i'<=`n' {
 local cltmp=ctrl1 in `i'
 g tmp=abs(`cltmp'-tract90)
 sort tmp
 while `j'<=`k'-1 {
  local temp=``j'' in 1
  if `temp'!=. {
   mat C1[`i',`j']=`temp'
  }
 local j=`j'+1
 }
 sort tractid
 drop tmp
 local j=1
 local i=`i'+1
}
local i=1
while `i'<=`n' {
 local c2tmp=ctrl2 in `i'
 g tmp=abs(`c2tmp'-tract90)
 sort tmp
 while `j'<=`k'-1 {
  local temp=``j'' in 1
```

```
   if `temp'!=. {
    mat C2[`i',`j']=`temp'
   }
  local j=`j'+1
  }
  sort tractid
  drop tmp
  local j=1
  local i=`i'+1
 }
 mat DTC1=T-C1
 mat DTC2=T-C2
 mat DC2C1=C2-C1
 keep in 1/`n'
 keep tract90 ctrl1 ctrl2
 svmat DTC1
 svmat DTC2
 svmat DC2C1
 svmat BAD
 drop if BAD1==1
 local i=1

 log using `infile'.log, replace

 while `i'<`k' {
  display "Treated-Control 1 difference in ``i''"
  ttest DTC1`i'=0
  local i=`i'+1
 }
 local i=1
 while `i'<`k' {
  display "Treated-Control 2 difference in ``i''"
  ttest DTC2`i'=0
  local i=`i'+1
 }
 local i=1
 while `i'<`k' {
  display "Control 2-Control 1 difference in ``i''"
  ttest DTC2`i'=0
  local i=`i'+1
 }

 log close

 end
```

APPENDIX D

Alternative Matching Specifications

Matching results obtained from the basic specification are less than perfect when other non-matching characteristics are considered. This raises a question whether the spillover hypothesis tests results are conclusive; i.e, the disparity in employment growth rates are caused not by spillovers, but other uncontrolled characteristics of census tracts. The basic matching specification, however, can be used as a basis for comparison with other matching specifications, and in this way, the robustness of test results can be examined.

In this appendix, matching results of several alternative specifications are discussed. Table D.1 shows alternative specifications that were tested, and summarizes matching problems that occurred. A common problem with many specifications is the difficulty in matching due to the lack of control candidates with similar characteristics. This problem is particularly severe in the case of matching for the second control group. For example, property values, rents and proportion of population with a Bachelor's degree in the treated area are in general significantly lower than in the two control areas. Moreover, the distributions of population in certain income and ethnic groups in the treated area are quite different particularly from the second control area – e.g. there is a substantially higher proportion of Black population in South Central Los Angeles neighborhoods than in San Gabriel and San Fernando Valleys. Consequently, many specifications that yield satisfactory matching results for the first control group may fail to deliver the same results for the second control group.

Matching specifications that are highlighted in Table D.1 produce satisfactory matching results, i.e., all *t*-tests and *F*-test accept the Null hypotheses that matching characteristics of treated and control groups are the same. The results of these specifications are reported in section 3.5.3 in Chapter 3.

Table D.1 Summary of Alternative Matching Specifications

Spec.	emp9080	ret9080	pop9080	retfr90	empd90	popd90	pblck90	phisp90	mdhhinc	pcapinc	pbach	pnobach	md_rent	md_val	Problems & Notes
[redacted]															
Matched2	x	x	x										f2		
Matched3	x	x	x	x										f2	hf2
Matched4	x	x	x	x	f1			x			f2			f2	
[redacted]															
Matched6	x	x	x	x	x	f2									hf2
Matched7	x	x	x	x	f1	f2		f2		f2		f2		f2	
Matched8	x	x	f2	x	f1			x			f2		f2		hf1,2
[redacted]															
Matched11	x	x	x	x	x				x			f2	x		*
Matched12	x	x	x	x	x			x	f2				f2		*
Matched13	x	x	x	x	x				x				x		*
Matched14	x	x	x	x	x					f1,2			f1,2		**
Matched15	x	x	x	x	f1			x				f2	f2		hf2

Note:
x: used matching characteristics
f1: t-test fails to accept H0 for that characteristic in control I
f2: t-test fails to accept H0 for that characteristic in control II
hf1: F-test fails to accept joint H0 for all used matching characteristics in control I
hf2: F-test fails to accept joint H0 for all used matching characteristics in control II
*: used median rent/median HH income as matching characteristic
**: used median rent/per capita income as matching characteristic

As for other non-highlighted matching specifications, shown in Table 3.13, their matching results are quite problematic, especially for matching tracts in the treated group with the second control group because some characteristics of these two groups are extremely divergent. Notably, the average fractions of black population in 1990 in the treated, the first, and the second control groups are 0.36, 0.31, and 0.04, respectively. In addition, median property values in 1990 in the three groups are, on average, $139,000, $177,000, and $242,000. It is, therefore, quite impossible to use these variables as matching characteristics for the treated and the second control group because the *t*-tests would invariably reject the Null hypothesis. In some cases, inclusion of these variables might fail the *t*-tests of other matching characteristics, which would otherwise be easy to match, yet producing bad matching quality overall, such as in the case of matching specifications # 4, 7, and 8. In specification #8, the problem was so severe that even the joint hypothesis in the first control group was also rejected although it is usually accepted in other specifications.